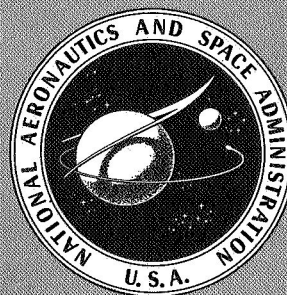


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PRELIMINARY RESULTS FROM AN OPERATIONAL 90-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM

CASE FILE COPY

A symposium held at
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA
November 17-18, 1970



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Langley Research Center
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Compiled by Albin O. Pearson and David C. Grana

Prepared by Langley Research Center



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

FOREWORD

A 90-day manned test of a regenerative life support system in a space station simulator was completed on September 11, 1970. This test was conducted by the McDonnell Douglas Astronautics Company, Western Division, under contract NAS1-8997 to the Langley Research Center, National Aeronautics and Space Administration. A number of unique investigations and studies were also conducted as an integral part of the test with the principal investigators provided by other NASA centers, Department of Defense, Department of Transportation, Atomic Energy Commission, industry, and universities. Preliminary results obtained from this test were presented at a symposium held at the Langley Research Center, Hampton, Virginia, on November 17 and 18, 1970. Most of the investigators involved in the test, including those from McDonnell Douglas Astronautics Company and the Langley Research Center, presented their initial findings at this symposium, and these presentations are compiled in this document. It is emphasized that these results are preliminary in nature, and it is expected that more detailed, final reports will be issued at later dates.

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RATIONALE FOR INTEGRATED LIFE SUPPORT SYSTEMS

Walton L. Jones, M.D.

NASA Office of Advanced Research and Technology

1

The purpose of this paper is to discuss the rationale for future integrated life support systems. Much professional effort has been expended in the past year on the 90-day manned run and this effort has made a real contribution to the space program. All the participants have, at the same time, been equally concerned with environmental problems. In the efforts to provide a closed ecology in a space cabin, the possibilities of applying these same concepts to earth's problems have been recognized. The resulting conservation of the economic and human resources will be most rewarding. It is an exciting matter to contemplate the development of technologies that may one day purify the waters of the earth and provide techniques for handling the ever more complex problems of waste disposal. It is believed that some of the most vexing problems now faced by the present society will be solved by the technologies which are the responsibility of the participants in this conference. In order to accomplish these goals within a reasonable time frame, there must be a careful coordination of industry and government efforts.

Figure 1 briefly summarizes the status of life support research and the progress expected to support missions in the 1980 to 1985 time period. The elements shown are familiar to those closely involved in expediting these research efforts.

The approach to reliable system development, as is well known, must proceed through several steps, from the conceptual stage, through subsystem development, component-based tests, and finally integrated tests of total systems. The 60-day test indicated at the left of figure 1 demonstrated for the first time in an integrated manned run that potable water could be recovered from urine and that man could consume this water without detriment to his health. In addition, the test demonstrated that unscheduled maintenance could provide a partial answer to the redundancy problem.

The 90-day test is now complete and confidence in the ability to ultimately maintain man in a controlled ecology in the environment of space for chosen periods is being gained. However, it has indicated the need for automatic control, modular configuration, and the usefulness of a larger crew for future longer ground tests. These tests will be most important, for cost will prohibit the building of complicated systems for extended tests in space flight. The answers must be determined economically here on the ground. These tests would proceed in logical increments. The first test might be the 180-day test that has been considered; later, a year-long test may be possible.

The identification of the most competitive subsystems for such successive steps must be accomplished through extensive ground tests that will yield valuable performance data and experience. The 90-day test has, for example, singled out pacing technological problems. These problems must be solved before the 180-day ground test can begin.

However, it must be remembered that in spite of all technical expertise, both in space and on earth, man is the most important component of the system. Life support systems which control his ecology must, therefore, obviously be designed to interrelate man's needs and capabilities closely. A number of elements above and beyond superior hardware design must be considered. The need to protect man's physical and psychological health will affect design considerably. For example, the full impact of exposure to prolonged weightlessness on the human organism is not known. More definitive testing will be needed to tell whether some system of artificial gravity will be required. If this system does prove to be a need, the impact on the life support system design will be substantial. As other human-oriented constraints become identified, they will also have to be considered. Upper limits of toxic gases, the importance of preserving in-flight samples of biological wastes for analysis, the psychological significance of volume constraints, food and water requirements, and the like, all affect regenerative system design.

In addition to the problems of identifying the medically significant factors for space missions, developing and designing effective subsystems, and selecting the most appropriate combinations for specific missions, there is a final requirement to study carefully the interrelation or interfaces of the equipment and the crew. The efficiency of the man-machine interface design represents an important variable in the determination of overall system efficiency. Equipment built for use or operation by humans must be designed in terms of the best available information concerning human capabilities, preferences, and frailties. Fortunately, a significant body of information of this class now is available in large part as a result of intensive research efforts conducted under the auspices of the National Aeronautics and Space Administration.

ADVANCED LIFE SUPPORT SYSTEM DEVELOPMENT PLAN

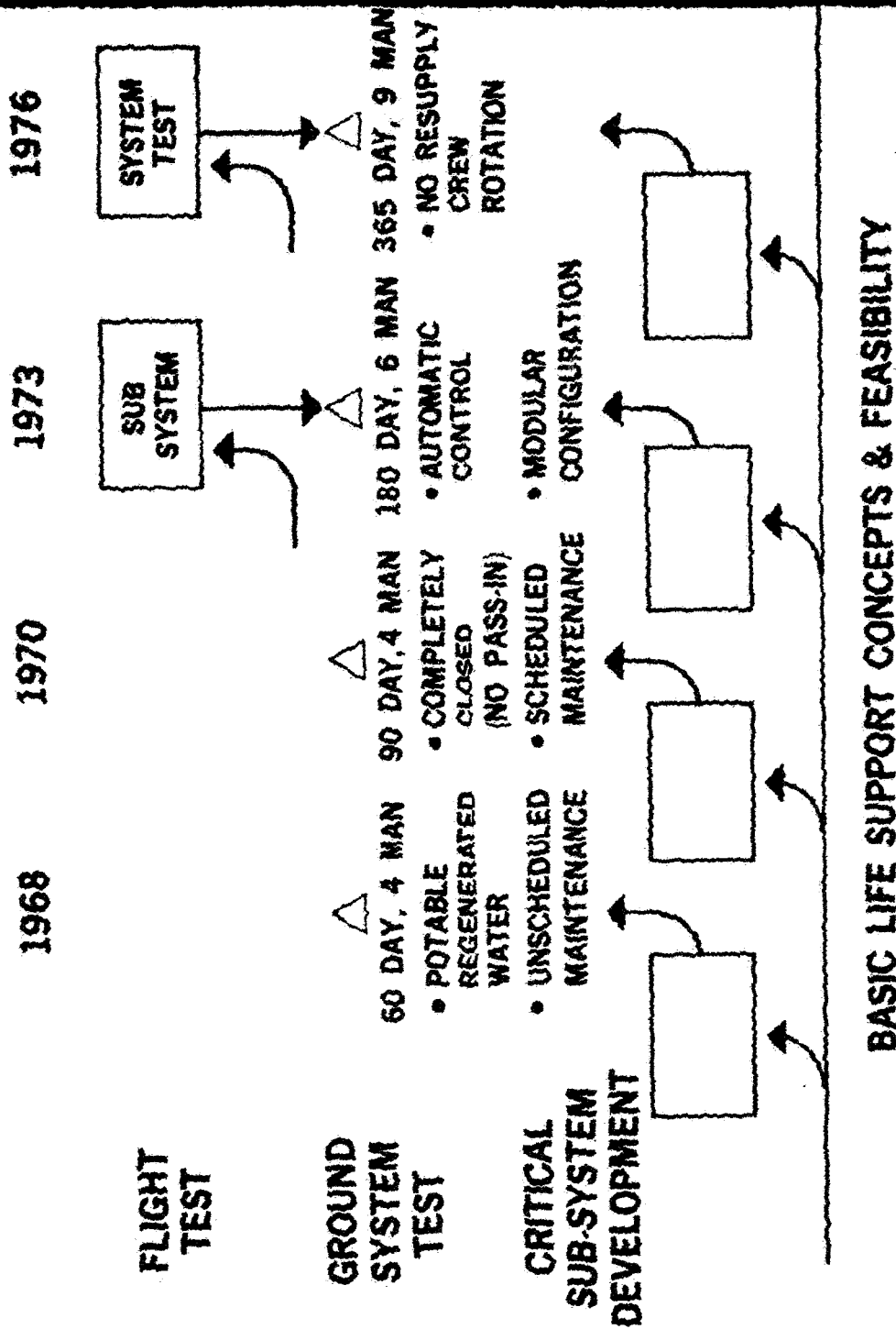


Figure 1

TEST OBJECTIVES AND PROGRAM MANAGEMENT

by J. K. Jackson

McDonnell Douglas Astronautics Company

2

SUMMARY

Objectives of the 90-day operational manned test involved the evaluation of an advanced regenerative life support system similar to that of an orbiting scientific laboratory under closed-door conditions. These objectives included determination of long-term operating characteristics and power requirements of individual subsystems and the total system; measurement of mass and thermal balances; determination of the ability of the test crew to operate, maintain, and repair onboard equipment; measurement of chemical and microbial equilibrium of the closed ecological system; assessment of the effect of confinement on the psychological and physiological characteristics of the test crew; and collection of data to assist in determining the precise role of man in performing in-flight experiments.

To implement the performance of this test a program management team was established by McDonnell Douglas Astronautics Company (MDAC). This group, headed by a Program Manager, included the necessary technical and scientific specialists to plan and execute the test program. The Program Manager reported to MDAC Senior Management and also served as the principal technical interface with the NASA program personnel.

INTRODUCTION

In the development of life support systems for advanced manned spacecraft, extended manned tests of integrated systems provide valuable data on the performance of subsystems under continuous operating conditions, the ability of the crew to operate and maintain them, and the requirements of the crew for maintenance of their physiological and psychological health for efficient accomplishment of mission objectives.

The following papers present the results of such a test, for a period of 90 days, using an advanced operational regenerative life support system under closed-door conditions. The test, performed in a Space Station Simulator (SSS), included the evaluation of a number of advanced life support subsystems with backup provided by alternate subsystems that had undergone extensive manned testing. Data were obtained on the performance of the equipment, the men, and the man-system interface. The test was performed by MDAC under the direction of the NASA Langley Research Center and sponsored by the NASA Office of Advance Research and Technology. Results obtained by a number of other contractors and investigating agencies will also be presented.

Previous tests of complete, manned life support systems have been performed by MDAC for a period of 60 days in the Space Station Simulator (refs. 1, 2, and 3) and by the NASA for 28 days in the Integrated Life Support System (ILSS) (ref. 4). The experience gained in performing these tests, and others of shorter duration, was applied in planning for the 90-day test. Features that were incorporated included advanced criteria for selection of the test crew, design of crew quarters, logistics planning, selection and design of subsystems, and data acquisition. These features were derived from the previous tests and assisted in improving the realism of the operational simulation, as well as increasing the confidence in test completion and attainment of detail data for use in design of operational life support systems.

TEST OBJECTIVES

The 90-day test was planned to obtain complete data in the interacting effects of the crew and the life support system. To obtain these data, the following objectives were established:

- A. To demonstrate a capability to operate a multi-man life support system in a continuous regenerative mode for a 90-day period without resupply. The system must provide a habitable atmosphere, food and water for nutritional support, and personal accommodations consistent with man's needs in the areas of personal hygiene, waste management, comfort and health. The system will include regenerative oxygen and water loops. It will be a goal to minimize the amount of stored expendable materials required for the test.
- B. To obtain total life support system and subsystem performance characteristics which include a material balance, a thermal balance, and power requirements.
- C. To operate with no materials passed into or out of the test chamber for the maximum possible duration to permit the chemical and microbiological characteristics of the atmosphere, processes and hardware to reach operating equilibrium under man-loaded conditions and to determine the capability of the system and crew to operate without resupply. If resupply is required, it will continue to be an objective to hold the passing in and out of materials to a minimum and whenever feasible, materials to be passed into the chamber will be sterilized.
- D. To demonstrate man's capability to perform in-flight maintenance as a means of increasing system reliability and to demonstrate the capability for in-flight monitoring of the necessary human, environmental, and system parameters.

- E. To obtain through skillful planning, timelining, conducting, and analyzing pertinent onboard crew work activities, data which will assist in determining the precise role of man in performing in-flight experiments; assist in determining the practical benefits of manned activity in space; and assist in validating mathematical models of space missions.
- F. To obtain data on physiological and psychological effects of long-duration exposure of the crew to confinement in the cabin atmosphere; on long-term group dynamics; and on crew work rest cycles.
- G. To evaluate a number of advanced life support subsystems, using the proven subsystems of the SSS as backup, obtaining operating experience and performance data under continuous testing and realistic conditions of manned loads and subsystem interaction.

PROGRAM ORGANIZATION

In order to manage the planning and operation of the test for MDAC, the program organization shown in figure 1 was established. Reporting to the program manager was a staff of specialists in technical and scientific areas to provide assistance in planning and execution of the test. His assistant was the Test Medical Director, responsible for the manned testing and medical aspects of the program. Business management support was also provided in areas of contracts, administration, and financial control. The program manager reported through the Chief Engineer of the Advance Biotechnology and Power Department to the MDAC senior management and served also as the principal point of contact with NASA for exchange of technical information.

Figure 2 shows the relationship of the 90-day test program organization to the MDAC senior organization structure. Although the direct line of command was through the Advance Systems and Technology Subdivision, extensive support to the program was provided by the Development Engineering Subdivision. This support principally included the provision of facilities and technical services by the Engineering Laboratories Department and constitution and review of the Operational Readiness and Inspection Committee which reviewed the test planning and documentation from a standpoint of operational safety and presented findings to the Vice President/Development Engineering and to the NASA Langley Operational Readiness Review Committee.

TEST CREWMEN

The four men who manned the SSS during the 90-day test performed many services which were essential to its successful completion. Among these services were the collection of much of the data on mass balance, performance

of highly skillful repairs on equipment, patient compliance with scheduled task assignments, collection and management of medical samples and physical data, and provision of much relevant psychological data by answering questionnaires and operation of performance testing devices. Table 1 shows basic information on these men. The four backup crewmen who underwent the same training program and assisted in operations during the test also were a major factor in the program.

CONTRIBUTING AGENCIES

Many contributions to the success of the 90-day test were made by scientists and engineers from many Government agencies, universities, and industrial organizations, listed in Tables 2, 3, and 4, respectively. Representatives of many of these organizations will present resumes of their findings in following discussions. It is sincerely regretted that it is not possible for all to participate at this time. Much credit is due to those who are unable to participate in this discussion, as well as those who are included.

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4. Pecoraro, J.W., Pearson, A.O., Drake, G.L., and Burnett, J.R.: Contribution of a Developmental Integrated Life Support System to Aerospace Technology. AIAA Paper No. 67-924 presented to AIAA Fourth Annual Meeting at Anaheim, California, October 23-27, 1967.

TABLE I
INFORMATION ON CREWMEN

CREWMEN	AGE	ACADEMIC DISCIPLINE(S)	DEGREE(S)	SCHOOL(S)	RELEVANT EXPERIENCE
STEPHEN DENNIS	23	LIFE SCIENCES, NEUROBIOLOGY AND BEHAVIORAL GENETICS	BS, 1969 TOWARD MS	MIT CALIFORNIA INSTITUTE OF TECHNOLOGY	BIOCHEMICAL AND MICROBIOLOGICAL SKILLS
TERRY DONLON	31	CHEMISTRY PHYSICAL CHEMISTRY MEDICAL PHYSICS	BS, 1961 MS, 1964 PHD, 1970-1	REED COLLEGE WASHINGTON STATE UNIVERSITY UCLA	RADIOISOTOPE TECHNICIAN CLINICAL MEDICINE LABORATORY TECHNICIAN
JOHN HALL (CREW COMMANDER)	26	CHEMISTRY MEDICINE GEOCHEMISTRY GEOCHEMISTRY	BA, 1965 2 YEARS MS, 1968 TOWARD PHD	REED COLLEGE HARVARD MEDICAL CALIFORNIA INSTITUTE OF TECHNOLOGY	ELECTRONICS INSTRUMENTATION REPAIR TECHNICIAN SMALL GROUPS IN ISOLATION (ALASKA AND PERU)
WILSON WONG	22	MECHANICAL ENGINEERING AERONAUTICS	BSME, 1969 TOWARD MS	CCNY CALIFORNIA INSTITUTE OF TECHNOLOGY	REPAIR AND TEST OF OIL REFINERY HARDWARE

Table 2
PARTICIPATING GOVERNMENT AGENCIES

<u>NASA-Headquarters (OART)</u>	<u>USAF-Aerospace Medicine Laboratory</u>
Direction	VD-VF Water Recovery
	Commode
<u>NASA-LRC (Langley)</u>	<u>AEC/Mound Lab</u>
Direction	Pu-238 Radioisotope Heaters
Two-Gas Control	
Four-Gas Spectrometer	<u>U.S. Army/Natick Labs</u>
EEG	Freeze-Dried Foods
Breath Analysis	
Crew Selection	<u>NASA-MSFC (Huntsville)</u>
Psychomotor Tester	CO ₂ Study
Microbial Sensor	Habitability Evaluation
Mission Analysis	Skylab Light Level
Zero-g Porous Plate H ₂ O Separator	
Solid Amine CO ₂ Concentrator	<u>USN-Submarine Medical Research</u>
Pulmonary Function	<u>Laboratory (Groton)</u>
Zero-g Humidity Control	CO ₂ Blood Studies
Water Electrolysis	
Psychoacoustics	<u>USN-Neuropsychiatric Research</u>
Microbiologic Analyses	<u>Institute (San Diego)</u>
	Crew Selection
<u>NASA-ARC (Ames)</u>	EEG Studies
Critical Task Tester	
Visual Tester	<u>U.S. Department of Transportation</u>
Response Tester	Particulate Sampling
Glycerol Experiment	
<u>NASA-MSC (Houston)</u>	<u>Naval Medical Research Institute</u>
Apollo Water Dispenser	Blood Analysis
Urinal	Crew Selection
Tissue Dispenser	EEG Studies
Teflon-Coated Fiber glass	
Fluorel/Refset Elastomers	
Apollo-Type Crew Suits	
Fireproof Games	
Fireproof Paper	
PBI Fabrics	
Virus/Mycoplasma Analyses	
Vitamin D Assays	

Table 3
PARTICIPATING UNIVERSITIES

University of California at Los Angeles

Noninterference Performance Analysis

Test Crewmen

University of Chicago

Pico Library and Projectors

Medical College of Virginia

Potable Water Virology

Texas Christian University

Crew Selection Criteria

California State College at Long Beach

Psychodiagnostics

Test Crewmen

California Institute of Technology

Test Crewmen

University of Southern California

Test Crewmen

Table 4
CONTRIBUTING CONTRACTORS

<u>Aerojet-General</u>	<u>Mine Safety Appliances</u>
Trace Contaminant Analysis	Toxin Burner
<u>General Electric</u>	<u>Scheufelin Papierfabrik Company</u>
Commode	Fireproof paper
<u>Litton (Atherton Division)</u>	<u>Perkin-Elmer</u>
Microwave Oven	Four-Gas Mass Spectrometer
<u>Litton (Stouffer Foods)</u>	<u>Dupont</u>
Frozen Prepared Foods	Teflon-Coated Fiber glass
<u>MDAC-West</u>	<u>Monsanto</u>
Thermal Control	Heat Transfer Fluid (Coolanol 35)
Urine Collector	<u>Monsanto Chemstrand Division</u>
Air Evaporator Water Reclamation	Durette Fabrics
Molecular Sieve CO ₂ Concentrator	<u>Monsanto Research/Mound</u>
Sabatier Reactor	<u>Laboratories</u>
Two-Gas Control	Radioisotope Heaters
Life Support Monitor	<u>Massachusetts General Hospital</u>
Wash Water Recovery	Vitamin D Assays
<u>Lockheed</u>	<u>Hamilton-Standard</u>
Zero-g Humidity	Solid Amine CO ₂ Concentrator
Water Electrolysis	<u>B. Welson</u>
<u>Central Laboratories (Pico-Rivera)</u>	Apollo-Type Crew Suits
Clinical Analyses	<u>Parker Brothers</u>
<u>AiResearch</u>	Fireproof Games
Sabatier Reactor	<u>Celanese Corporation</u>
LiOH CO ₂ Removal	PBI Fabrics
Apollo H ₂ O Dispenser	<u>System Technology, Inc.</u>
<u>3M Company</u>	Critical Task Tester
Fluorel/Refset Elastomers	
<u>Allis-Chalmers</u>	
Water Electrolysis	
<u>Aurora Engineering</u>	
Autoclave Pass-Through	

Table 4 (Continued)

<u>General Dynamics Corporation</u>	<u>Fabric Research Corporation</u>
Response Analysis Tester	Apollo-Type Crew Suits
<u>Oregon Freeze Dry</u>	<u>Webb Associates</u>
Freeze Dried Foods	
<u>Computer Communications, Inc.</u>	Metabolic Rate Meter
Acoustic Data Link	
<u>Warren E. Collins</u>	<u>Douglas Aircraft Company</u>
Bicycle Ergometer	Behavioral Acoustics

90-DAY TEST PROGRAM ORGANIZATION

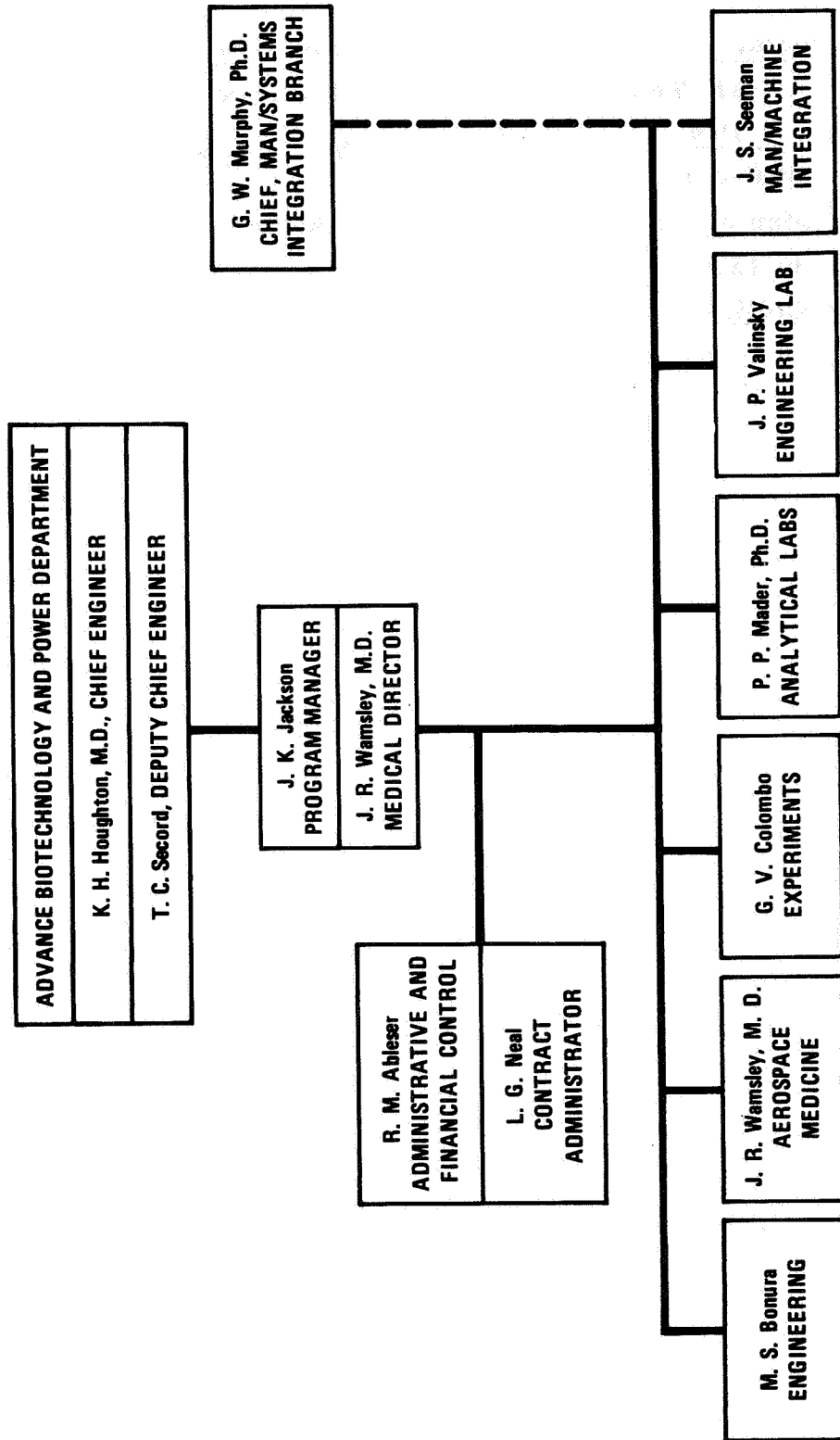


Figure 1.

MDAC ORGANIZATION STRUCTURE RELATIVE TO 90-DAY TEST

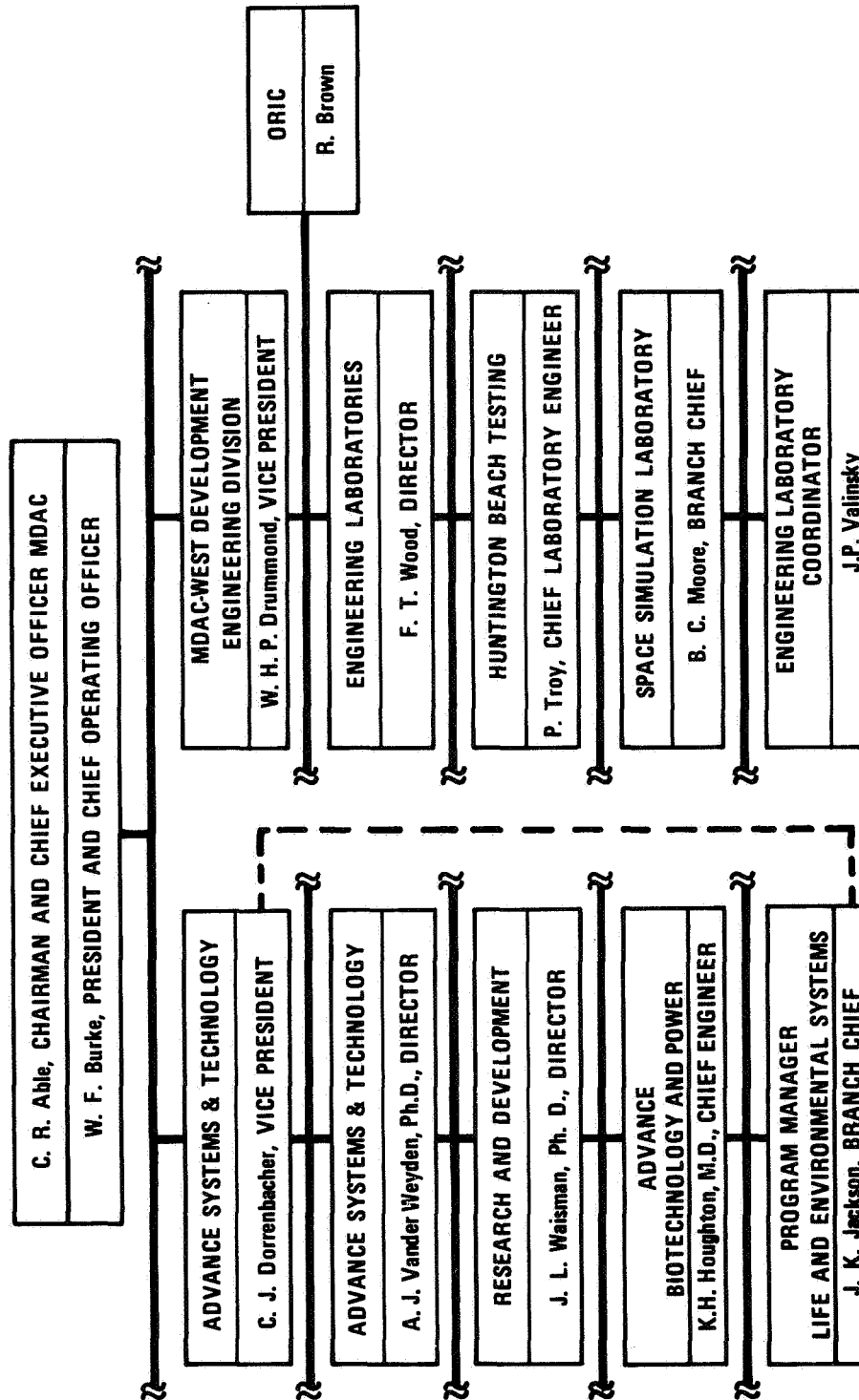


Figure 2.

FACILITY SUPPORT SYSTEMS

By J. P. Valinsky, R. L. Malin, and N. R. Radke

McDonnell Douglas Astronautics Company

SUMMARY

The facility for a 90-day manned test of a regenerative life support system is described including the support systems which were assembled to satisfy the program objectives and the safety requirements. Specific systems and equipment that are included are: the Space Station Simulator (SSS) chamber, the heating and cooling heat transfer loops, the electrical power system, the vacuum and freeze trap systems, the gas analysis system, the communications system, and the data system.

A review of the significant chronological events and resulting solutions will be discussed; also pertinent data, conclusions, and recommendations will be presented.

The supporting laboratories which included microbiological, water analysis, and medical, are described and their effectiveness is discussed.

INTRODUCTION

The facility systems for the 90-day manned test provided a test bed for the life support equipment and crew and the personnel protection provisions required to insure a safe test.

The facility supplied electrical power, heating and cooling fluids, gaseous nitrogen, and vacuum capability to the life support systems. Facility systems monitored the life support system performance and all the parameters critical to crew safety. Outside laboratories were used to provide medical analysis and to support the chemical and microbiological laboratories.

The SSS (table 1) consists of a closed chamber and equipment necessary to evaluate a four-man crew and their life support systems under simulated Earth orbital space station conditions.

The SSS chamber is a double-walled cylinder, 12 ft in diameter and 40 ft long. The 4,100-ft³ chamber contains a 150-ft³ air lock and two 18-in.-diameter pass-through air locks, one equipped with an autoclave for microbiological control during pass-through operations. The chamber is operated at reduced atmospheric pressures to duplicate planned space cabin gas compositions. The annular space between the inner and outer walls is evacuated to slightly below cabin pressure, ensuring that all leakage is outboard to provide realistic testing of environmental control and life support equipment. Chamber leakage averaged less than 1 lb/day during previous tests. The

chamber is provided with 4 in. of thermal insulation to minimize heat transfer and acoustic transmission. In the chamber, the noise-generating life support systems and experiments are separated from the crew living and recreation area by an acoustical barrier wall.

COOLANOL SYSTEMS

The cooling and heating requirements for the SSS life support and environmental control subsystems are fulfilled by two fluid conditioning and transport units. The cooling fluid facility (table 2) provides Coolanol 35 at 34° F to the thermal control unit, the carbon dioxide concentrators, the potable and wash water recovery unit, the Sabatier unit, and the electrolysis unit. The fluid heating facility (table 3) provides Coolanol 35 at 235° F or 350° F to the carbon dioxide concentrators.

The cooling fluid facility is located outside the SSS and consists of a 90-gallon insulated storage tank; two Freon refrigeration systems to cool the Coolanol 35; a circulation pump for each system to force Coolanol 35 through the evaporator coils and back to the storage tank; and an external plumbing system, with two pumps in parallel, to supply the Coolanol 35 to the SSS and return it to the storage tank.

The heating fluid facility is also located outside the SSS and includes a 45-gallon insulated storage tank, a 15-kW immersion heater within the tank to heat the Coolanol 35, a powerstat to control the voltage to the heater, a thermostat to control the temperature of the Coolanol 35 within the storage tank, and a circulation pump.

ELECTRICAL POWER

The electrical power required for operating the SSS subsystems and the support facilities includes the following (table 4):

- A. 400-cycle, 120/208-volt, three-phase.
- B. 60-cycle, 440-volt, three-phase (not available inside SSS).
- C. 60-cycle, 115-volt, single-phase.
- D. 28-volt dc.

In addition, backup power is provided by a 400-cycle standby motor generator set, a 28-Vdc power supply and an emergency 28-Vdc battery-operated system. The battery system is normally under a regulated trickle charge, but will automatically supply power to critical circuits if the primary 28-Vdc supply is terminated.

VACUUM FREEZE TRAP SYSTEM

The vacuum freeze trap system consists of two parts (table 5). One portion, the waste management vacuum system, serves the commode unit

of the waste management subsystem and the CO₂ concentrator during bakeout cycles on the molecular sieves. The vacuum distillation-vapor filtration (VD-VF) vacuum system services the VD-VF potable water recovery unit. These systems are separated to prevent any possible bacterial contamination of the potable water system by the waste management system.

The waste management vacuum system (fig. 1) consists of two mechanical roughing pumps, two cold traps, and a system for controlling the temperature and flow rate of gaseous nitrogen through coils in the cold traps. The VD-VF vacuum system is very similar in arrangement and operation to the waste management vacuum system. It consists basically of two small cold traps, two vacuum pumps, and various valves and plumbing. The cold traps share the same temperature control system as the waste management vacuum system.

GAS ANALYSIS

The composition of the SSS atmosphere during the manned operation was determined on a continuous basis and by individual samples taken at frequent intervals (table 6). Continuous analysis was performed by the gas analysis console (fig. 2).

Representative samples of cabin air, taken from one of 24 preselected locations (fig. 3), are compressed to sea-level pressure in the gas analysis console and can be withdrawn by syringe and needle technique for detail analysis by gas chromatograph or measured quantities can be passed through a liquid nitrogen freeze-out trap for concentration of organic trace contaminants.

COMMUNICATIONS

The SSS communications system provides visual and auditory links between operating staff and crew members (table 7 and fig. 4) for:

- A. Monitoring the health and well-being of the crew at all times.
- B. Transmission of audio-visual repair and maintenance information to the SSS crewmen.
- C. Provision of information for evaluation of man-machine interactions during manned tests.
- D. Transmission of commercial TV and taped entertainment to crewmen.
- E. Recording of video and/or audio information from selected areas within the SSS.
- F. Recording of video and audio information during emergency situations.
- G. Control of all communications from one central console.

- H. Outside telephone communication from normal intercom stations.
- I. Private channels of communication from selected intercom stations.

INSTRUMENTATION AND DATA ACQUISITION

The major systems used to acquire and display data, shown on figure 5, are:

- A. Low speed data system (LSDS).
- B. Life support monitor console (LSMC).
- C. Acoustical data link.

Table 8 is a summary of data recorded on this system.

The LSDS is a self-contained, general-purpose data acquisition and recording system. It accepts analog data from 10 mV to 5 volts, converts the data to digital values, and records on magnetic tape.

The LSMC consists of a wide variety of signal conditioning and data display instruments. This console provides on-line data displays and the audio and visual alarms of critical parameters.

The acoustical data link provided a remote computer terminal that was used to transmit and receive data to and from a remote computer using standard telephone lines.

The terminal inside the SSS at the command console was used to summon crew subroutines and control the entry of raw data. It was also used to display stored information as required by the crew.

MICROBIOLOGICAL LABORATORY

At specified intervals throughout the course of the test, microbiological analysis was performed on samples of potable water, wash water, station surfaces, station atmosphere, and the nose and throat of the crew members. All equipment necessary for the collection and culture of the water samples was stored on board (table 9).

CHEMICAL LABORATORY

Chemical analysis of atmospheric trace contaminants, potable and wash water were performed in the laboratory located in same building as the SSS. Potable water samples were sent to the chemical laboratory at Santa Monica for metal analysis (table 10).

MEDICAL LABORATORY

The medical laboratory was used to prepare samples for shipment to the supporting laboratories (table 11).

SAFETY AND OPERATIONAL READINESS

Safety and operational readiness reviews were conducted in preparation for manned testing in accordance with established MDAC procedures (Control Procedure CP 5.061-C) and with NASA Langley Research Center Management Manual Instructions 1710.1, 1710.2, and 1710.3. The sequence of events for these reviews is shown in figure 6.

The MDAC Operational Readiness Inspection Committee (ORIC) was constituted by and reported to Mr. W. H. P. Drummond, Vice President of Development Engineering for MDAC-West. Membership of the ORIC was composed as shown in table 12. This committee provided a continuous and complete review of the safety aspects of the test during the planning stages, covering the subject matter shown on table 13. Tables 14 and 15 show some of the safety equipment included inside the SSS and nearby. Results of the ORIC review were presented to Mr. Drummond and to the NASA Operational Readiness Review Committee.

The Operational Readiness Review Committee (ORR) was constituted by NASA LRC with Mr. H. A. Wilson as chairman. In addition to review of the test safety aspects, as presented by the ORIC, this committee also reviewed the test readiness from the standpoint of meeting contractual objectives.

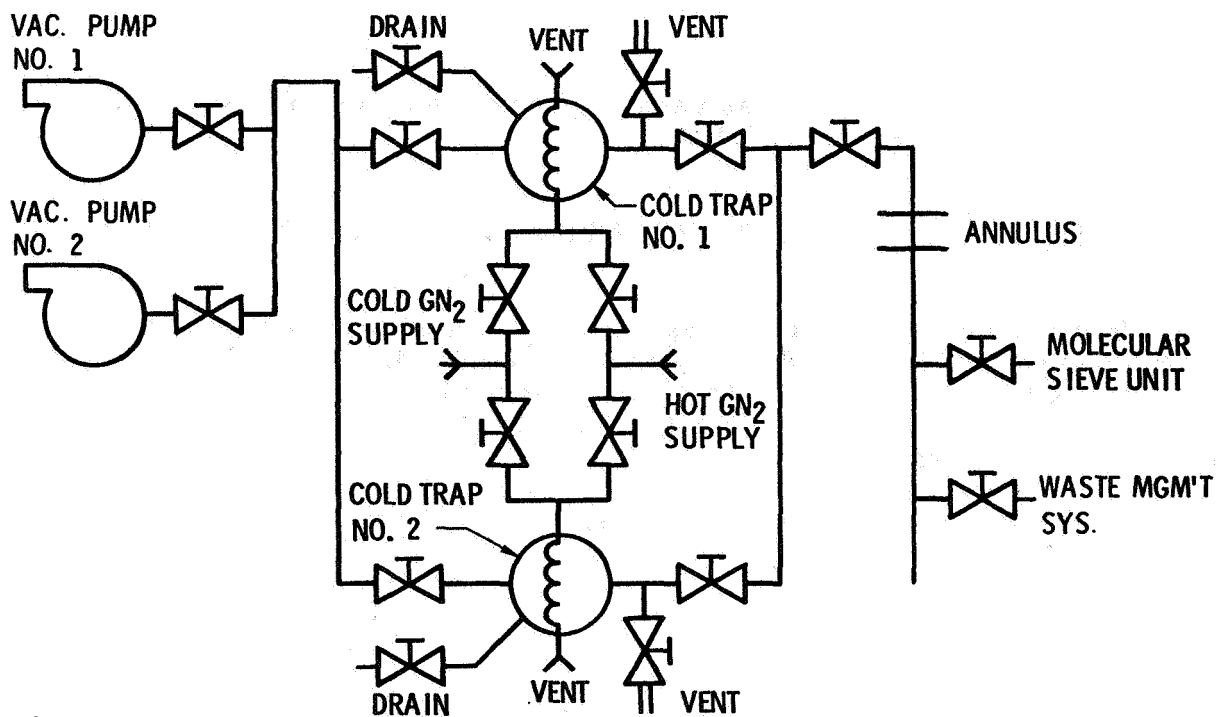


Figure 1.- Waste management vacuum system plumbing schematic.

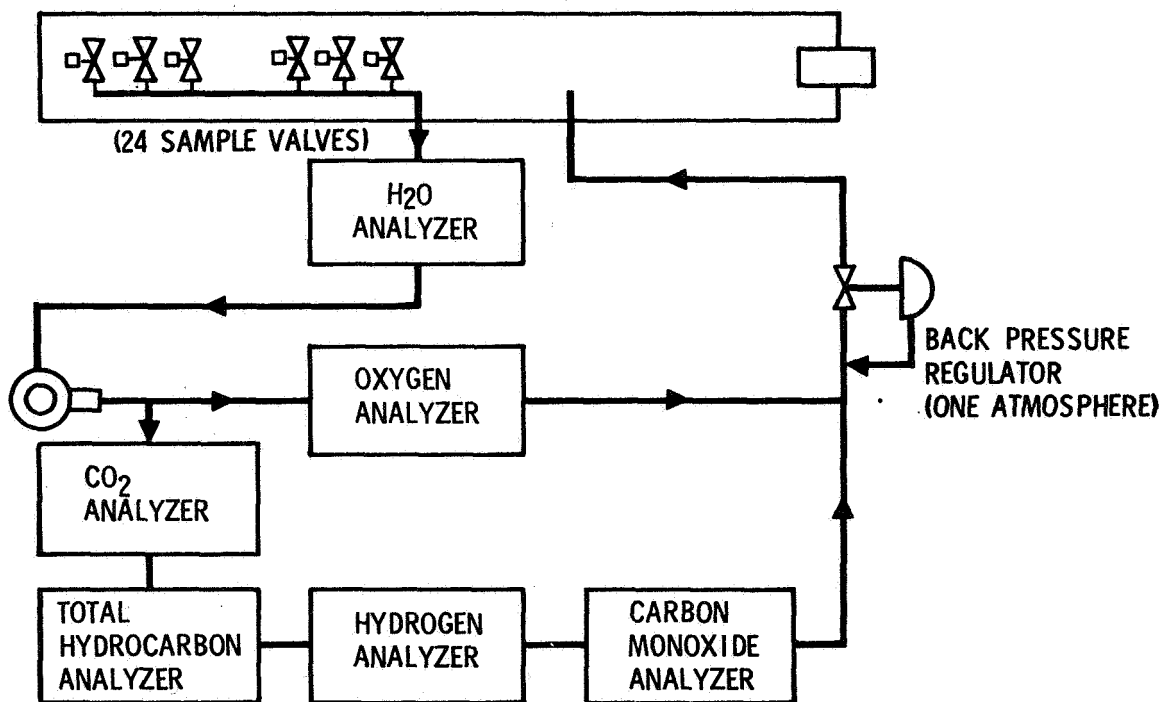
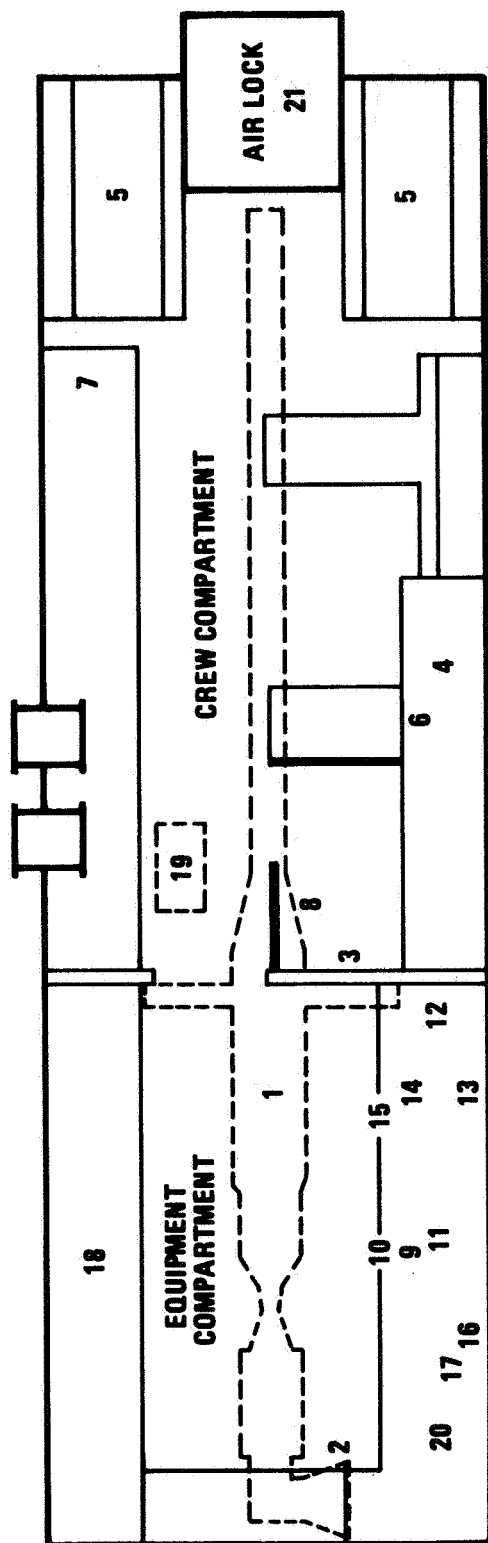


Figure 2.- Gas analysis console system.



CHANNEL NO.	LOCATION	CHANNEL NO.	LOCATION
1.	THERMAL CONTROL DUCT HX OUTLET	12.	AIR EVAPORATOR BLOWER OUTLET
2.	EQUIPMENT AREA	13.	AIR EVAPORATOR CHARCOAL BED INLET
3.	WASTE MANAGEMENT AREA	14.	AIR EVAPORATOR CHARCOAL BED OUTLET
4.	FOOD PREPARATION AREA	15.	AIR EVAPORATOR CONDENSER OUTLET
5.	BUNK AREA	16.	TOXIN CONTROL OUTLET
6.	FOOD STORAGE CABINET NO. 15	17.	SABATIER CASE
7.	FOOD STORAGE CABINET NO. 73	18.	SOLID AMINE EXHAUST
8.	COMMODE BLOWER OUTLET	19.	ELECTROLYSIS H ₂ TANK AREA
9.	CO ₂ CONDENSER SEPARATOR DISCHARGE	20.	ELECTROLYSIS CASE
10.	CO ₂ HEAT EXCHANGER INLET	21.	AIR LOCK
11.	MOLECULAR SIEVE OUTLET		

Figure 3.- Location of GAC gas sampling points.

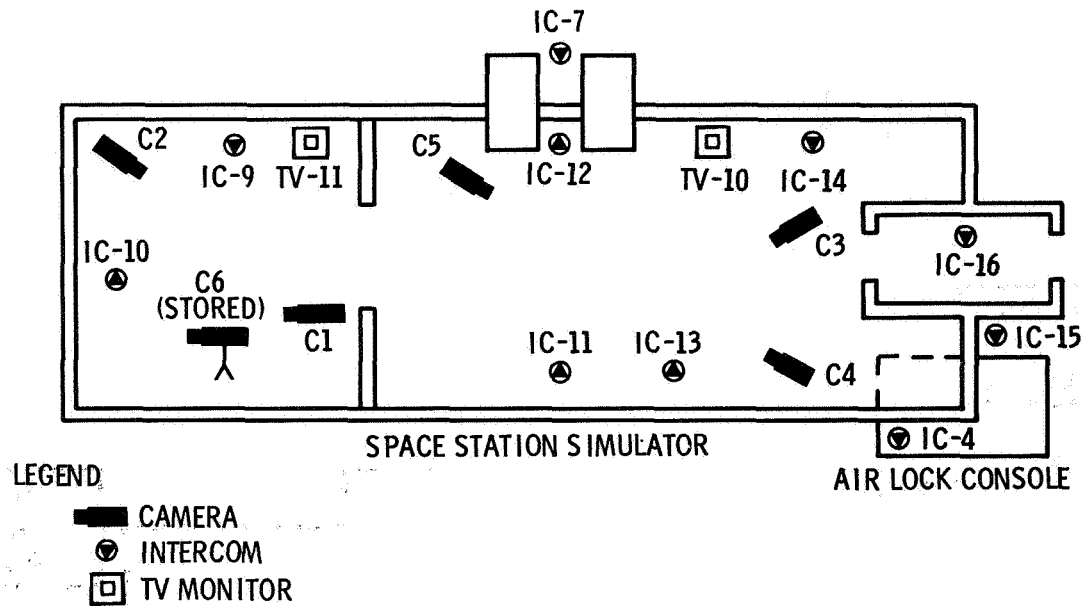


Figure 4.- Space station simulator communications.

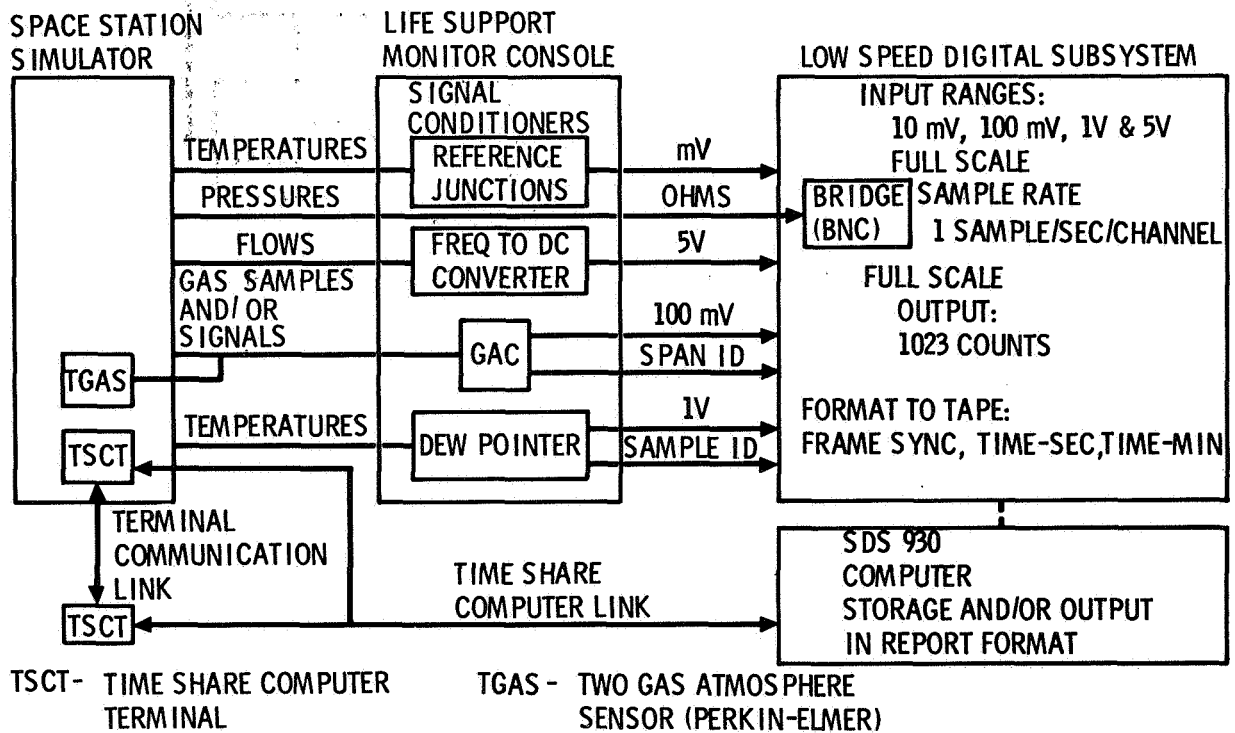


Figure 5.- Life support instrumentation data management subsystem.

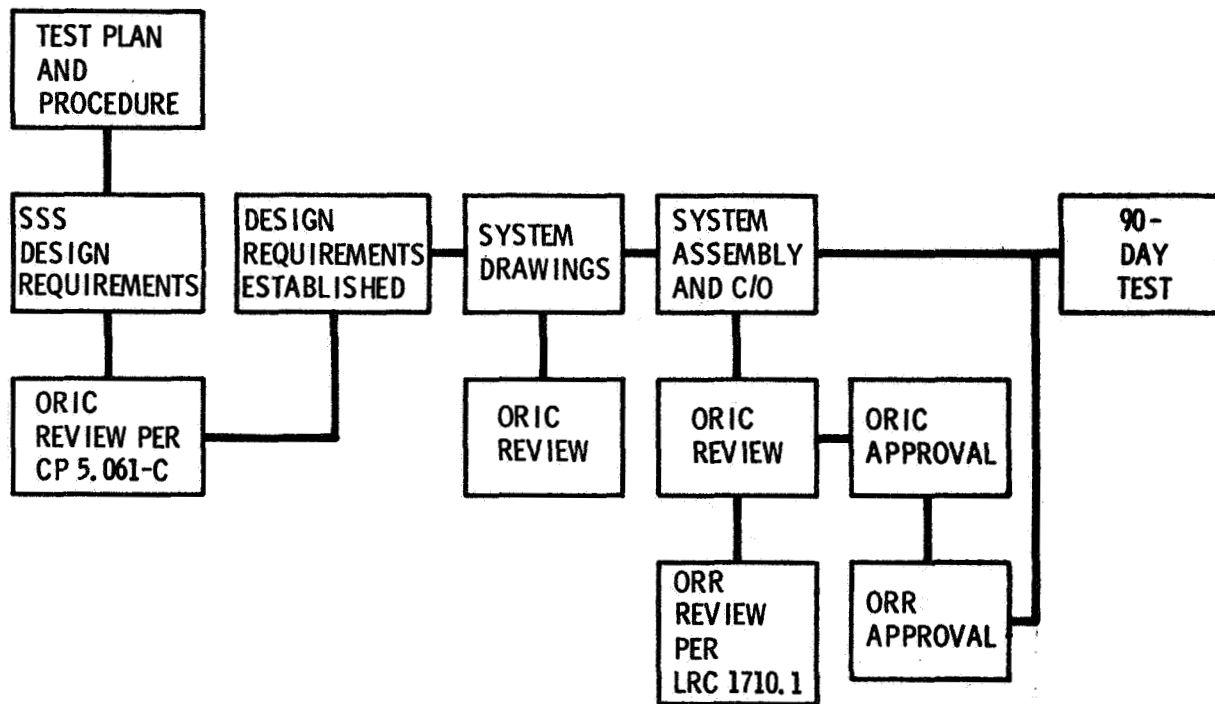


Figure 6.- Operational readiness review flow chart.

TABLE 1
CHAMBER AND HABITABILITY FEATURES

CHAMBER VOLUME		4100 CUBIC FEET, 116 CUBIC METERS
CHAMBER PRESSURE	10 PSIA	517 TORR
CHAMBER TO ANNULUS ΔP		5 INCHES H ₂ O, 9.3 TORR
AVERAGE TEMPERATURES		
CREW AREA		74 ⁰ F
BUNK AREA		73 ⁰ F
EQUIPMENT AREA		78 ⁰ F
AIR VELOCITY CREW AREA		17 FT/MIN
AVERAGE DEWPOINT		58 ⁰ F
MEDIAN LIGHT LEVELS		
SKYLAB 1ST MONTH		6 FOOT-CANDLES
CREW'S SETTING 3RD MONTH		23 FOOT-CANDLES

TABLE 2
COLD COOLANOL 35 SYSTEM

OPERATING PARAMETERS

DELIVERY TEMPERATURE	34 ⁰ F
DELIVERY PRESSURE	100 PSIG
TOTAL FLOW RATE	12 GALLONS/MINUTE
AVERAGE HEAT LOAD	44,000 BTU/HOUR

SYSTEMS SERVICED

THERMAL CONTROL
 POTABLE H₂O RECOVERY AND HUMIDITY CONTROL
 SABATIER
 ELECTROLYSIS
 CO₂ CONCENTRATOR
 VD-VF H₂O RECOVERY
 SOLID AMINE
 ISOTOPE STORAGE

TABLE 3
HOT COOLANOL 35 SYSTEM

OPERATING PARAMETERS

DELIVERY TEMPERATURE	235 ⁰ F, 350 ⁰ F
DELIVERY PRESSURE	50 PSIG
TOTAL FLOW RATE	5 GALLONS/MINUTE
HEAT SUPPLIED	14,000 BTU/HOUR

SYSTEMS SERVICED

CO₂ CONCENTRATOR - MOLECULAR SIEVE
- SOLID AMINE

SYSTEM FAILURES

VALVE DIAPHRAGMS	SEA LEVEL C/O
QUICK DISCONNECTS	UNMANNED BASELINE
SUPPLY PUMP	90-DAY TEST

TABLE 4
ELECTRICAL POWER

TYPE	AVERAGE LOAD
120/208 VOLTS, 400 Hz, 3 PHASE	2700 WATTS
110 VOLTS, 60 Hz, 1 PHASE	3450 WATTS
28 VOLTS, DIRECT CURRENT	1680 WATTS

EMERGENCY POWER

30 VOLT 200-AMPERE HOUR TRICKLE CHARGED BATTERY SYSTEM
REDUNDANT BUILDING POWER SERVICE/AUTOMATIC SWITCHOVER

POWER FAILURES	DURATION
4-26-70 UNMANNED BASELINE TEST	5 SECONDS
7-22-70 40TH DAY 90-DAY TEST	3 SECONDS
8-8-70 57TH DAY 90-DAY TEST	8 SECONDS

TABLE 5
VACUUM FREEZE TRAPS

• **WASTE MANAGEMENT AND MOLECULAR SIEVE**

FREEZE TRAP TEMPERATURE	-70° TO -125°F
FREEZE TRAP PRESSURE	200 MICRONS
AVERAGE DAILY H ₂ O LOAD	0.58 POUND

• **VD-VF SYSTEM**

FREEZE TRAP TEMPERATURE	-70° TO -125°F
FREEZE TRAP PRESSURE	5 TORR
AVERAGE DAILY H ₂ O LOAD	0.47 POUND

TABLE 6
GAS ANALYSIS

GAS ANALYSIS CONSOLE

CO ₂	INFRARED
H ₂ O	INFRARED
CO	INFRARED
TOTAL HYDROCARBONS	FLAME IONIZATION
OXYGEN	PARAMAGNETIC
HYDROGEN	CATALYTIC OXIDIZER

GAS CHROMATOGRAPHS

WET CHEMICAL ANALYSIS

ATMOSPHERE CONTAMINANT SAMPLING SYSTEM

FREEZE TRAPS
CHARCOAL ADSORPTION
DIRECT GAS SAMPLES

OZONE DETECTOR

TABLE 7 COMMUNICATIONS

AUDIO

16 STATION 3 CHANNEL INTERCOM WITH 2 CHANNEL RECORDING
TELEPHONE
AM/FM RECEIVER

CLOSED-CIRCUIT TV

INSIDE SPACE STATION SIMULATOR

5 FIXED CAMERAS WITH MICROPHONES, 1 PORTABLE CAMERA
2 TV MONITORS

TEST CONTROL AREA

1 PORTABLE CAMERA
8 TV MONITORS, 1 STANDARD BROADCAST RECEIVER
2 VIDEO TAPE RECORDERS
VIDEO SPECIAL EFFECTS GENERATOR

SYSTEM PROBLEMS

IMAGING ON VIDICON TUBE
AUDIO BACKGROUND NOISE
HEAD SETS

TABLE 8 INSTRUMENTATION SUMMARY

ENGINEERING PARAMETERS RECORDED

TEMPERATURES	120
PRESSURES	18
FLOW	23
DEWPOINT	3
ATMOSPHERE	5
EVENTS	37
WEIGHT	10
ELECTRICAL POWER	7

BIOMEDICAL PARAMETERS

EKG
ORAL TEMPERATURE
METABOLIC RATE
ERGOMETER WORKLOAD
HEART RATE

TABLE 9
MICROBIOLOGICAL LABORATORY

- REYNIER AIR SAMPLERS
- SURFACE SWABS
- POTABLE H₂O
- WASH H₂O
- NOSE AND THROAT
- SKIN
- POST 90-DAY TEST SAMPLES - CREW AND HARDWARE

TABLE 10
CHEMICAL LABORATORY

GAS ANALYSIS WET CHEMISTRY

DAILY - ALDEHYDES, AMMONIA, SO₂, NO₂
TWICE PER WEEK - H₂S, CL, HCL, PHOSGENE

WATER ANALYSIS

ONE SAMPLE PER TANK

TURBIDITY	AMMONIA
COLOR	TOTAL ORGANIC CARBON
TASTE	BROMINE
ODOR	HEXAVALENT CHROMIUM
FOAMING	

ONE SAMPLE PER TWO WEEKS

METAL ANALYSIS BY MDAC SANTA MONICA CHEMISTRY LABORATORY

TABLE 11
MEDICAL LABORATORY

COLLECTED AND PREPARED SAMPLES

BLOOD AND URINE	-	CLINICAL ANALYSIS	-	CENTRAL ANALYTICAL LAB
BLOOD	-	STRESS AND CO	-	NMRI
BLOOD	-	CO ₂ EFFECTS	-	SUBMARINE MEDICAL CENTER
THROAT CULTURES	}	VIRUS AND MYCOPLASMA	-	MSC
FECAL SAMPLES				
URINE SAMPLES				
POTABLE WATER		VIRUS		MED COLL VA
RESPIRATORY SAMPLES	-	ALVEOLAR GAS (EXPIRED AIR)		NASA LANGLEY
BLOOD SERUM		VITAMIN D		MSC

TABLE 12
OPERATIONAL READINESS INSPECTION COMMITTEE
ORIC

- CHAIRMAN
- EXECUTIVE SECRETARY
- ELECTRICAL ENGINEERING
- MECHANICAL ENGINEERING
- SAFETY
- QUALITY ASSURANCE
- AEROSPACE MEDICINE
- EMPLOYEE RELATIONS
- LEGAL

TABLE 13
SPACE CABIN SIMULATOR
FACTORS COVERED IN SAFETY REVIEW

PERSONNEL TRAINING
EMERGENCY EQUIPMENT AND PROCEDURES
MATERIAL SELECTION AND CONTROL
QUALITY ASSURANCE
DOCUMENTATION AND CONFIGURATION CONTROL
FAILURE EFFECTS ANALYSIS
OPERATING PROCEDURES
ELECTRICAL CIRCUIT DESIGN
MEDICAL MONITORING
FIRE DETECTION AND EXTINGUISHMENT

TABLE 14
EMERGENCY EQUIPMENT - INSIDE SSS

- | | |
|--|---|
| ● AIR PACK BREATHING EQUIPMENT | ● SMOKE DETECTOR SYSTEM (6) |
| ● POCKET RESPIRATORS | ● TRACE GAS MONITORING SYSTEM |
| ● CO ₂ FIRE EXTINGUISHERS (4) | ● EMERGENCY REPRESSURIZATION VALVE (CABIN) |
| ● PORTABLE LIGHT | ● EMERGENCY REPRESSURIZATION VALVE (AIR LOCK) |
| ● EMERGENCY LIGHTING SYSTEM (4) | ● AIR LOCK/CABIN EQUALIZATION VALVE |
| ● BACKUP INTERCOM SYSTEM | ● WARNING SIREN AND BELL |
| ● WATER SPRAY SYSTEM | |
| ● FIRE HOSES (2) | |

TABLE 15
EMERGENCY EQUIPMENT - OUTSIDE SSS

- | | |
|-------------------------------------|---|
| ● BATTERY POWER SUPPLY (28 VDC) | ● SSS POWER SHUTOFF SWITCH |
| ● BATTERY POWER LIGHTS | ● WARNING SIREN AND BELL |
| ● BACKUP INTERCOM | ● EMERGENCY ABORT SWITCH |
| ● REPRESSURIZATION VALVE (CABIN) | ● FIRE/SMOKE PROTECTIVE EQUIPMENT |
| ● REPRESSURIZATION VALVE (AIR LOCK) | ● CO ₂ EXTINGUISHER (100 LB) |
| ● AIR LOCK/CABIN EQUALIZATION VALVE | ● MEDICAL TREATMENT FACILITIES |
| ● CABIN OVERPRESSURE RELIEF VALVE | ● HOT-LINE TELEPHONE |

LIFE SUPPORT SYSTEMS

By J. K. Jackson

McDonnell Douglas Astronautics Company

SUMMARY

The interior of the Space Station Simulator was redesigned to provide an equipment room and a crew living area separated by an acoustic barrier. The life support equipment, operating instrumentation, and controls were located in the equipment room. Extensive provisions were made for acoustic control. The life support equipment included advanced units which were being operated for the first time in a manned test and baseline equipment which was available from the previously completed 60-day test. Integration of these units in such a manner that failure of a single unit did not jeopardize other test objectives was a major task of the systems engineers. The life support system included units for water management, thermal and humidity control, atmosphere purification, atmosphere supply and pressure control, waste management, and food management.

4

INTRODUCTION

The design requirements for the life support system used in the 90-day operational manned test included the following:

Total Pressure	10 ± 0.3 psia (517 ± 15 torr)
Oxygen Partial Pressure	3.0 ± 0.1 psia (155 ± 5 torr)
Cabin Temperature	$70^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ($294^{\circ}\text{K} \pm 2.8^{\circ}\text{K}$)
Relative Humidity	40 to 70 percent
CO ₂ Partial Pressure	0.0735 psia (3.8 torr)
Diluent:	Nitrogen

All crew equipment, tools, and expendables were stored onboard at the start of the mission, eliminating the need for pass-in operations. Pass-out operations of medical samples required to verify the health of the crew and a limited quantity of other material necessary for the collection of on-going test data were conducted once weekly through a small airlock equipped with an autoclave that was sterilized before each use.

SPACE STATION SIMULATOR DESIGN

Figure 1 shows the configuration of the chamber that was used during the 90-day test. This arrangement features an equipment room and crew living area separated by an acoustic barrier. The equipment room includes all the mechanical equipment of the environmental control system and its operating instrumentation. A command center is located at the "front" of this room including the crew life support monitor, a psychomotor test console, and the computer-link keyboard. Computer input and output are displayed on a large video monitor visible through the forward viewport, but outside the chamber for ease of installation and maintenance. The crew living area includes space for food preparation, a folding table for eating and recreation, an onboard laboratory area, and an enclosed waste management area. Two bunks are located on each side of the air lock and are isolated from the main area by Armalon draperies. Much of the design of this installation was influenced by previous test experience which indicated equipment and living areas should be separated and that efficient noise control is very important.

LIFE SUPPORT SYSTEM

The design of the life support system involved consideration of the requirement for compact installation with ready accessibility for maintenance and repair. The evaluation of the advanced subsystems required extensive integration with the previously tested backup subsystems. This ensured continuation of the test when a malfunction caused temporary or permanent shutdown of one or more of the advanced subsystems, without compromising the remaining test objectives. Figure 2 shows the interrelationships of most of the environmental control and life support units which will be described in more detail in the following discussion. These subsystems include:

Water Management and Humidity Control

Atmosphere Purification and Control

Atmosphere Supply and Pressurization

Waste Management

Food Management

Table 1 presents a list of the advanced subsystems and equipment that were evaluated, together with a list of backup and emergency units which were available for operation. In general, the advanced subsystems listed were not used previously in extended manned testing, or had undergone extensive revision since previous testing experience. They were used for

primary life support during the 90-day test. The backup subsystems had been extensively tested. Although they were redesigned for the 90-day test, this was intended to improve maintainability or improve data collection, or to meet installation requirements. The interrelation between the advanced subsystems and backup units is generally indicated on figure 2.

Detail descriptions of the life support subsystems and the results obtained from the 90-day test are presented in the following papers.

A breakdown of weights and volumes of major items of life support equipment used in the 90-day test is included in table 2. Generally these units were not designed to meet flight weight, reliability, or structural requirements. However, these values may serve as a general guide, although they probably are usually much larger than would be found in a flight type design.

Table 1

EVALUATION OF ADVANCED SUBSYSTEMS AND EQUIPMENT

	Advanced Subsystem	Backup Subsystem	Emergency
Potable Water Recovery	Vacuum Distillation-Vapor Filtration (AMRL)	Open-loop Wick Evaporator	Onboard storage
Carbon Dioxide Concentrator	Solid Amine Adsorber (LRC-Hamilton Standard)	Molecular sieve	LiOH
Water Electrolysis	Alkaline Electrolyte (Allis-Chalmers)		Electrolyzer
	Circulating Electrolyte (LRC-Lockheed)		
Atmosphere Supply Control	Flight-Weight Two Gas Control (LRC-MDAC)	Breadboard Two-gas control	
Atmosphere Composition Sensor	Mass Spectrometer Sensor (LRC-Perkin Elmer)	Beckman Polarographic (O ₂) Statham Strain Gage (Total)	
Waste Management	"Slinger" Commode (AMRL-General Electric)		
Food Preparation	Microwave Oven (Litton)		

TABLE 2
WEIGHT AND VOLUME OF LIFE SUPPORT EQUIPMENT

SUBSYSTEM	UNIT	WEIGHT (LB)	VOLUME (CUFT)
WASTE MANAGEMENT	COMMODE	101	8.5
	URINE COLLECTOR	65	4.0
WATER MANAGEMENT	VD-VF: BOILER	65	
	RADIATION SHIELD	150	
	SHIELD WATER	400	15
	HUMIDITY CONTROL/WICK EVAPORATOR	253	27
	POTABLE WATER TANKS (6)	240	12
	WASH WATER RECOVERY	50	2
	WASH WATER TANKS	80	4
ATMOSPHERE PURIFICATION	SOLID AMINE	650	18
	MOLECULAR SIEVE	517	20
	THERMAL CONTROL	240	36.5
ATMOSPHERE SUPPLY AND CONTROL	SABATIER/TOXIN BURNER	170	10
	ALLIS-CHALMERS ELECTROLYSIS	220	6
	LOCKHEED ELECTROLYSIS	285	10
	FLIGHT-WEIGHT TWO-GAS CONTROL	8	1
	BREADBOARD TWO-GAS CONTROL	50	7
	MASS SPECTROMETER	40	3.5

SPACE STATION SIMULATOR ARRANGEMENT FOR 90-DAY TEST

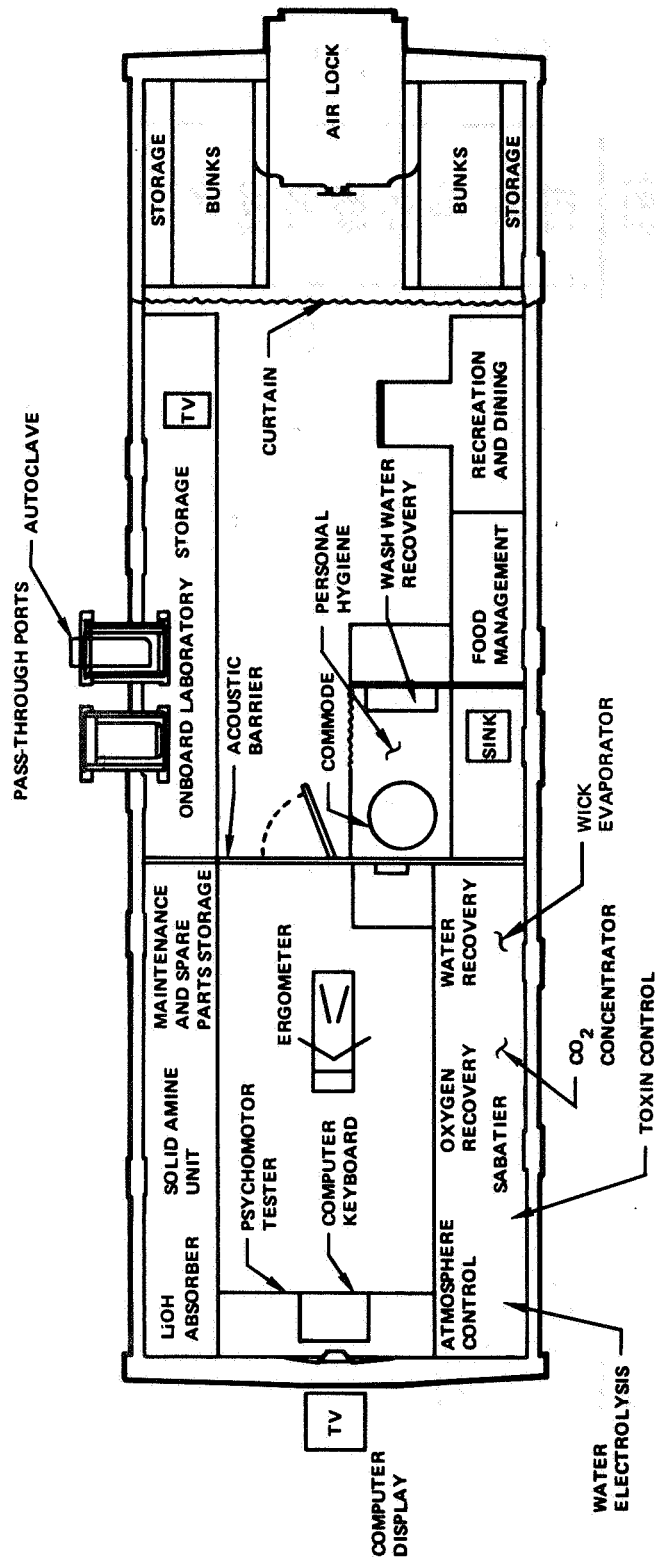


Figure 1.

MAJOR UNITS OF LIFE SUPPORT SYSTEM SPACE STATION SIMULATOR

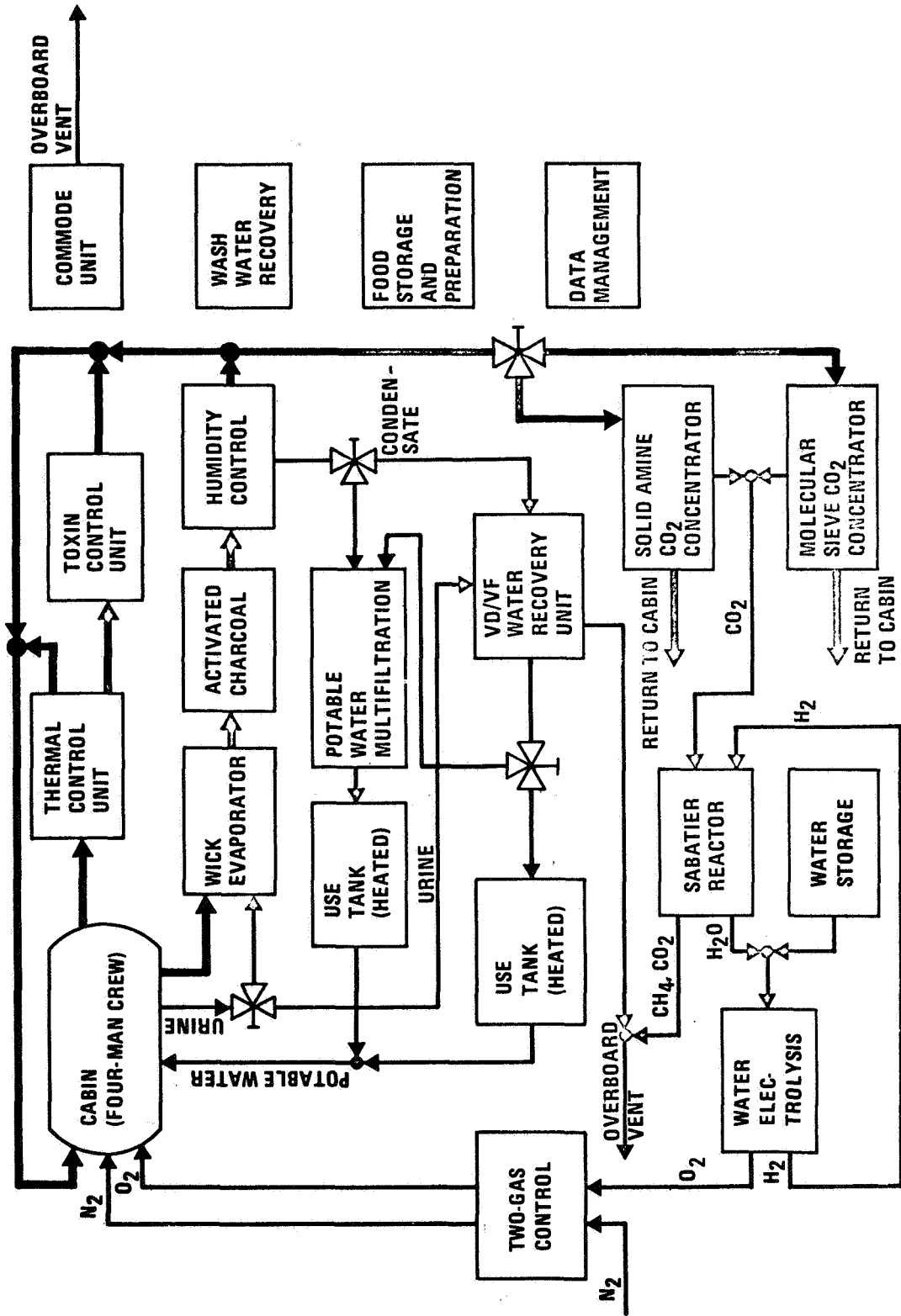


Figure 2.

WATER MANAGEMENT

By D. F. Putnam, E. C. Thomas,
and G. V. Colombo

McDonnell Douglas Astronautics Company

SUMMARY

Water management subsystems used in the 90-day test were: (1) isotope-heated VD-VF unit; (2) wick evaporator and humidity control unit; (3) detoxification-multifiltration unit; (4) potable water storage and distribution system; (5) backup potable water supply; and (6) wash water recovery unit. The performance data include mass and energy balances, water chemistry, and microbiological profiles. Pretest qualification procedures are covered as well as operating procedures used during the manned test.

INTRODUCTION

This paper is one of a series that describes the results of a 4-man, 90-day test conducted in the McDonnell Douglas Space Station Simulator with closed water and oxygen loops and no resupply. All expendables including food, pretreatment chemicals, filter beds, and machinery spare parts were stored onboard the SSS and no pass-ins were made during the test.

SUBSYSTEM DESCRIPTIONS

The water management subsystems are shown in figures 1 through 6. Figure 1 is a schematic which shows the interfacing between subsystems. Figure 2 is a photograph of the isotope-heated vacuum distillation-vapor filtration (VD-VF) unit and the wick evaporator and humidity control unit, as installed in the SSS. Figure 3 is a schematic of the wash water recovery unit, which was completely isolated from the potable water units. Figure 4 is a photograph of the wash water recovery unit showing the sink and the multifiltration columns. Figure 5 is a photograph of the potable water storage and distribution system. The insulated, heated, storage tanks were hung from the overhead. A part of the quick-disconnect water transfer and line-up station can be seen at the right of figure 2. Figure 6 is a schematic of the potable water storage and distribution system. It shows the MDAC cold water dispenser and the parallel plumbed Apollo hot and cold water dispenser. Figure 6 also shows the backup potable water supply, which did not have to be used during the test.

These subsystems are described in more detail below.

VD-VF Unit

The basic components of this unit were the urine accumulator, VD-VF boiler, water condenser, five radioisotope heat source capsules (plutonium-238 dioxide), and a radiation barrier water tank. The VD-VF unit recovered potable water from pretreated* urine and humidity condensate through the use of radio-isotope heat sources. Four of the five heat sources of $^{238}\text{Pu O}_2$, each producing approximately 75 watts of thermal energy, were used in the boiler section to vaporize the urine mixture at about 100°F and 0.93 psia. The resulting vapor then passed through a porous matrix of Teflon and stainless steel wire mesh and was superheated to 265°F by the fifth isotope heat source of about 50-watt output. The vapor then passed through a catalyst bed, along with a small amount of bleed air supplied to oxidize the vaporized impurities to carbon dioxide and water vapor. The water was then condensed and stored in an accumulator while the noncondensable gases were vented to an overboard vacuum cold trap. When the condensed water was chemically and microbiologically acceptable, it was pumped directly to a storage tank. During periods of unacceptability because of taste, odor, or microbiological contamination, it was pumped to the detoxification-multifiltration unit for further processing.

Radiation shielding was provided by a movable water jacket, which is shown in figure 5. A shielded, cooled storage facility was also provided inside the SSS for storage of the isotope capsules after removal from the VD-VF boiler.

Wick Evaporator Unit

The basic components of this unit are six wick packages, blower, carbon filter, particulate filter, and zero-g condenser separator.

This unit was used as a backup for the VD-VF unit for recovering potable water from urine, processing excessive humidity condensate not used by the VD-VF unit, and for humidity control. When used to recover potable water from urine, the pretreated urine was pumped to one of the wick packages where heated cabin air from the blower evaporated the water, leaving the urine solids in the wick. The water vapor then passed through the carbon and particulate filters and through the condenser separator where the water was removed and pumped to one of two zero-g holding tanks in the detoxification-multifiltration unit. The water was held at 160°F (344°K) for a 6-hour bacterial kill time and then multifiltered to one of the use tanks.

When the unit was used for humidity control only, the air flow was bypassed around the wicks to the condenser separator. The separator in this unit, built by Lockheed Missile and Space Company, operates on a hydrophobic-hydrophilic principle. A fine mesh Teflon-coated stainless steel screen is

*The nominal urine pretreatment was 4 ml/l of the following solution:
39.8 percent H_2SO_4 , 47.3 percent H_2O , 9.8 percent CrO_3 , 3.1 percent CuSO_4 , density = 1.42 g/ml.

the hydrophobic element in the air stream, and an uncoated stainless steel screen is the hydrophilic element for removing the separated water.

The separated water could be removed in either of two ways: (1) a negative pressure cylinder, with a spring force equal to the hydrophilic screen differential pressure rating, was filled from the separator and then pumped to one of the two holding tanks or (2) the negative pressure cylinder could be filled by utilizing the differential pressure sensing switch and pumping system supplied as part of the condenser separator unit.

Detoxification-Multifiltration Unit

The detoxification-multifiltration unit consisted of two zero-g holding tanks in which water was held for a minimum time of 6 hours at 160°F, a 1-micron filter followed by an activated carbon column, two ion-exchange columns, and a final activated carbon column. Each column contained approximately 0.2 lb of material.

Potable Water Storage and Distribution System

This system consisted of four heated zero-g storage tanks, distribution panel, circulation pump, 1-micron filter, chiller, MDAC dispensing unit, and Apollo hot and cold water dispensing unit. The system is shown schematically in figure 6.

The four storage tanks are shown hanging from the overhead in their installed positions in figure 5. Figure 2 shows the flexible quick-disconnect lines on the distribution panel. The four storage tanks were used in 48-hour rotational sequence according to a plan in which the status at any time was one tank being filled, one tank being chemically and microbiologically checked, one tank certified potable awaiting use, and one tank being used.

The distribution panel (fig. 2) contained movable piping connections and valving to place each of the potable tanks in its proper status. It also provided for a convenient location to draw samples at any time from any tank for microbial and chemical analyses.

The circulation pump provided a continuous flow of hot water from the use tank to the use point and return, to prevent bacterial growth during nonusage in an otherwise stagnant line.

Backup Potable Water Supply

The backup potable water supply consisted of a stainless steel tank containing 400 lb of iodine-treated distilled water. This water was to be used in the event of complete failure of both the VD-VF unit and wick evaporator unit to produce potable water. The iodine level was maintained at 5 ppm to provide microbiological control.

Wash Water Recovery Unit

This unit used multifiltration and heat sterilization to recover water for personal hygiene, laundry, and miscellaneous housecleaning chores. The basic components of this unit were two zero-g heated water tanks, multifiltration module, heat exchanger, sink with mixing supply valve, pump, washer and dryer. Basic H, a concentrated organic, nondetergent, biodegradable cleansing agent was used in the unit. A schematic of the system is shown in figure 3. The multifiltration module consisted of a 30-, 3-, and 1-micron filter series followed by an activated carbon column, two ion-exchange resin columns, and a final activated carbon column.

In operation, the used water was pumped from the sink to the first heated tank and then processed automatically through the multifiltration module to the second heated tank and is then ready to be reused. The manually operated mixing supply valve proportioned the amount of water through the heat exchanger to provide the desired temperature.

PRETEST QUALIFICATION

Prior to the start of the 90-day test, the water management system was operated with real urine for 3 weeks to obtain mechanical, chemical, and microbiological certification. The chemical results are shown in table 9 and the microbiological results are shown in table 1. During the checkout procedure, high levels of cadmium were initially found in water from tanks 4 and 5. A thorough inspection disclosed that a cadmium-plated brass fitting had inadvertently been installed in the discharge port of tank 4. It was also discovered that cadmium was leaching from a similar fitting in one of the VD-VF boilers. After both fittings were replaced, no further high cadmium levels were detected. A small amount of microbial contamination was found in two of the storage tanks (see table 1), but in repeated tests at a later date, no contamination was found. Both taste tests and consumption tests were run, with the crewmen participating, and the reclaimed water was found acceptable. A silver-ion generator, which had been installed in the system for microbiological control, did not pass qualification tests because of insufficient ion concentration and high microbe levels downstream of the generator.

The microbiological procedures used to qualify the system and produce the results shown in table 1 were in accordance with the National Academy of Sciences ad hoc Committee's recommendations for water quality standards for long-duration manned space missions (unpublished).

This committee recommended that microbiological sampling during system qualification include testing for aerobic organisms (both gram negative and gram positive), anaerobic organisms, fungal organisms, and viruses.

The procedure used for bacteria and fungi was that recommended in reference 1. All isolated organisms were subcultured to specific differential media for identification as shown in figures 7 and 8.

Testing Procedure for Bacteria and Fungi

For the standard pour plate procedure, each sample tested was collected, by use of sterile techniques in Whirl-Pac bags and labeled with the collection site and date of collection. Duplicate pour plate serial dilution cultures were done on each specimen, incubating one at 37° C for 48 hours for bacteria counts and one at 22° C (room temperature) for 7 days for fungi counts.

A presumptive test for coliforms, by means of lactose broth fermentation tubes, was also done using 2 ml of the original water sample.

One milliliter of each water sample was also inoculated into Thioglycollate Medium, which permits the growth of the strictest anaerobic as well as aerobic organisms.

Differentiation of Organisms

If aerobic growth appeared in the Thioglycollate Medium, this culture was subcultured onto Blood Agar, Eosin Methylene Blue Agar, and Staphylococcus Medium No. 110 for identification.

- A. Blood Agar is a general nondifferential medium which will grow both gram negative and gram positive organisms. This medium was used as a backup source for any organisms isolated.
- B. Eosin Methylene Blue Agar is a differential plating medium which is selective for gram negative organisms. Any organisms isolated on this medium were tested by means of biochemical reactions (such as citrate fermentation) for identification.
- C. Staphylococcus Medium No. 110 is selective for gram positive organisms, especially in the Staphylococcus group. Any growth on this medium was tested for the coagulase reaction which identifies Staphylococcus aureus.
- D. Fungus colonies which grew on the pour plate cultures incubated for 7 days at room temperature were identified by their colonial morphology.

Viruses

Analyses for viruses were conducted at Virginia College of Medicine. During the 90-day test all water was collected in sterile plastic bags from the Apollo hot water dispenser. Samples of approximately 250 ml were collected just prior to passout and stowed outside at -76° C until shipment.

OPERATING PROCEDURE

The protocol for maintaining the potable water system daily status and reclaimed water certification was as follows: water samples were delivered to the laboratory for analysis along with a chemical and physical analysis checkoff sheet (see fig. 9) and at the same time a Millipore Field Monitor was processed by the inside crew for bacterial analysis. The tank fill date and sample date were noted on a tank status card (see fig. 10) and as soon as available the chemical and microbiological results were also noted on the card and the medical director then certified or rejected the tank for consumption. The system status and progression of tanks from fill status through certification to final use status was kept current on a system status board as shown in figure 11.

The Millipore Field Monitors that were used for the enumeration and preliminary isolation of microorganisms were 0.45 μ , black, grid-type filters. Samples of water for microbial analysis were aseptically collected from each sampling port in a sterile disposable plastic bag after first flushing the sample port and then returning the initial 100 to 200 ml of water to the system via the urinal or sink. A fresh sterile field monitor and sampling tube assembly was used for each water sample cultured. After identifying the field monitors as to sample port, date, time, and volume of sample filtered (usually 10 ml), ampouled medium (Millipore^(R) M-TGE Broth) was added to each monitor and they were immediately incubated at 35°C for 48 hours. Following incubation the field monitors were opened and the membrane filters examined under illuminated low-power magnification for characteristic colonial growth. The total number of colonies present on each filter was counted and this count, divided by the volume of sample filtered, was recorded as the number of viable cells per milliliter of water. All field monitors showing growth at 48 hours were stored onboard at ambient temperature for weekly passout. In the outside laboratory, representative colonies were selected and subcultured from each monitor for identification of genus and species. Field monitors showing no growth onboard were returned to the original storage container and held at ambient temperature for the duration of the test.

PERFORMANCE

Overall Water Balance

A tabulated summary of the overall potable water balance is shown in table 2. It is significant that less than one-half of the reclaimed water was actually consumed by the crew. About one-fourth of the water was required to operate the solid amine unit and the remaining one-fourth was required to operate the VD-VF unit and for wash water makeup and samples. These data point up the need for realistic appraisals of the amount of reclaimed water that will ultimately be required in space vehicles in addition to the basic survival requirements of the crewmen.

Detailed water balances for several significant periods of the test are presented in paper 22.

VD-VF Unit

Two VD-VF boiler units were used during the test for a total of 63 days of operation. The first boiler was used for 25 days and the second boiler was used for 38 days, of which only the last 27 days were continuous operation. A total of 1,467 lb of urine and humidity condensate were fed to the units, which produced 1,353 lb of water for a water recovery efficiency of 94.3 percent. The net usable product was reduced to 1,309 lb because of sampling requirements and some substandard water that was rejected and reprocessed. Of this, 518 lb were used without multifiltration and 701 lb required multifiltration due to either poor taste or microbiological contamination.

The mass and energy balance and the expendable requirements for VD-VF boiler 1 are shown in table 3. The requirements for VD-VF boiler 2 are shown in table 4.

The major maintenance on this unit occurred after the switchover to the second boiler. The first problem occurred during the initial fill of the new boiler when it was observed that the float switch did not shut off the urine feed solenoid valve. Draining and disassembly of the boiler revealed that the float retainer was off the shaft and the float was completely free. Repair was completed and the boiler reassembled. During the next attempt to fill the boiler, the float switch wires were found shorted and a repair was made. The fill cycle was continued and the boiler overfilled and flooded the catalyst bed. This was thought to be the result of using the coarse Dwyer differential pressure switch circuit (normally used as a high boiler level warning light) to check out the float switch circuit, and then failing to return it to its proper status. The catalyst bed was removed, flushed with water, and then reassembled. A repeat of the flooded catalyst occurred and was found to be due to fused contacts on the float switch. Catalyst flushing and switch repair were performed again and the system restarted. A third flooding occurred after 11 days of operation. The urine accumulator was inadvertently allowed to run dry and the cabin pressure forced the urine out of the boiler. Again, the catalyst was flushed, the system was restarted and remained operational for 27 days. Figure 12 shows one of the boilers disassembled after the test.

The remaining maintenance requirements consisted of using the onboard steam sterilizer six times to sterilize the condensate tanks whenever bacteria contamination was observed. This procedure could not maintain condensate tank sterility during most of the operation on the second boiler, in which case the product water was reprocessed in the detoxification-multifiltration unit.

Wick Evaporator and Humidity Control Unit

The wick evaporator operated a total of 31 days as a backup to the VD-VF unit. The humidity control portion of the unit operated for the entire 90-day

test. The wick evaporator was fed 700 lb of pretreated urine, flush water, and miscellaneous input, and produced 680 lb of water for a water recovery efficiency of 100 percent. Five wick packages were used. A mass and energy balance and the expendable requirements are shown in table 5.

Premature flooding occurred in the first two wicks. The flooding was caused by a combination of (1) a higher feed rate than normal, and (2) unusually high humidity in the inlet air to the wick evaporator caused by the solid amine CO₂ removal unit. The high feed rate, which was more than double that required to process the daily urine production, was used in an attempt to deplete the accumulation of urine created during VD-VF unit shutdown. Figure 13 shows a typical disassembled wick package after the 90-day test.

The 24-lb air carbon canister satisfactorily removed all urine odors during the entire 90 days, and was not considered expended at the end of the test.

The zero-g condenser separator removed 3, 172 lb (35.2 lb/day) of humidity condensate and wick evaporator produced water. Of this water 525 lb overflowed the separator and was processed from an overflow catch basin, and results in a water separation efficiency of 83.5 percent. This efficiency is excellent considering the separator was handling more than 200 percent of its design capacity. The hydrophilic screen sumps (three installed in unit) required frequent removal and cleaning to minimize the amount of overflow. The frequency of cleaning varied, but averaged about every 3 days. Visual observation of the removed sumps did not reveal the cause of clogging.

The alternate method of feeding the negative pressure cylinder was required after day 83 when the cylinder spring broke. The alternate method operated satisfactorily the remainder of the test.

Detoxification-Multifiltration Unit

The detoxification-multifiltration unit processed 1, 839 lb of reclaimed water and humidity condensate. The contributions to this total were: 414 lb from the VD-VF unit, 358 lb from the wick evaporator, and 1, 067 lb of humidity condensate. The carbon and resin columns were changed three times during the test (see fig. 10). The reason for change was high NH₃ level on two occasions and rapidly increasing TOC* on the third occasion. A total of 1.2 lb of carbon and 1.2 lb of resin were expended. A performance summary of this unit is shown in table 6.

Potable Water Storage and Distribution System

This system operated satisfactorily for the entire test with the exception of the cold water supply ports in the dispensing unit which became bacterially contaminated and were not used after test day 3. The chemical (see fig. 14) and microbiological data are summarized in table 7, which shows the certified tank chemical and microbiological analyses. Table 8 summarizes all

*Total organic carbon.

the microbiological testing of the water management system done onboard during the test and table 9 shows the chemical analyses that were run biweekly during the test and also prior to the test during system qualification. The potable water daily inventory is shown in figure 15.

Backup Potable Water Supply

The backup potable water supply was not required during the test. Weekly checks of the iodine content were made to verify potability and the results of these analyses and a few microbiological checks are shown in table 10. Additional iodine was not required to maintain an acceptable minimum level.

Wash Water Recovery Unit

A summary water balance is shown in table 11 and results of the chemical, physical and microbiological analyses are shown on figure 16 and in table 12.

The unit processed 11, 182 lb of water and used 24 lb of expendables. The multifiltration module required four changes of a carbon column, one change of both resin columns, and replacement of five particulate filters at the time intervals shown on figure 16. Figure 17 shows the used filters. The necessary filter changes were dictated by their individual pressure drop increases and the column changes were dictated by crew judgment of water quality and chemical analysis results. The replacement of the filters and resin columns was a straightforward change, but the carbon column changes involved putting a new column in the last position and moving the old one into the first position.

In addition to the 710 lb of phase changed water that were added as makeup to the system, there was one complete change of water on day 35 in which the used charge was replaced with 88 lb of humidity condensate. This was done after the first signs of crew rejection of the water. Five days later on day 40, the first carbon column was changed and a considerable improvement in water quality was noted. Microbial growth was found in the felt pad carbon retainer in the carbon column and it is felt that this growth was responsible for the objectionable odors. Both the carbon and resin columns were changed on day 52 and probably would have been changed again on day 86 had it not been so close to the end of the test.

The washer and dryer were used to clean and dry 44 loads of wash composed of underclothing, socks, uniforms, wash cloths, towels, and bed sheets.

The power consumption of the wash water unit is shown in table 13.

REFERENCE

1. Standard Methods for the Examination of Water and Waste Water, American Public Health Association, 11th Edition, 1960, New York.

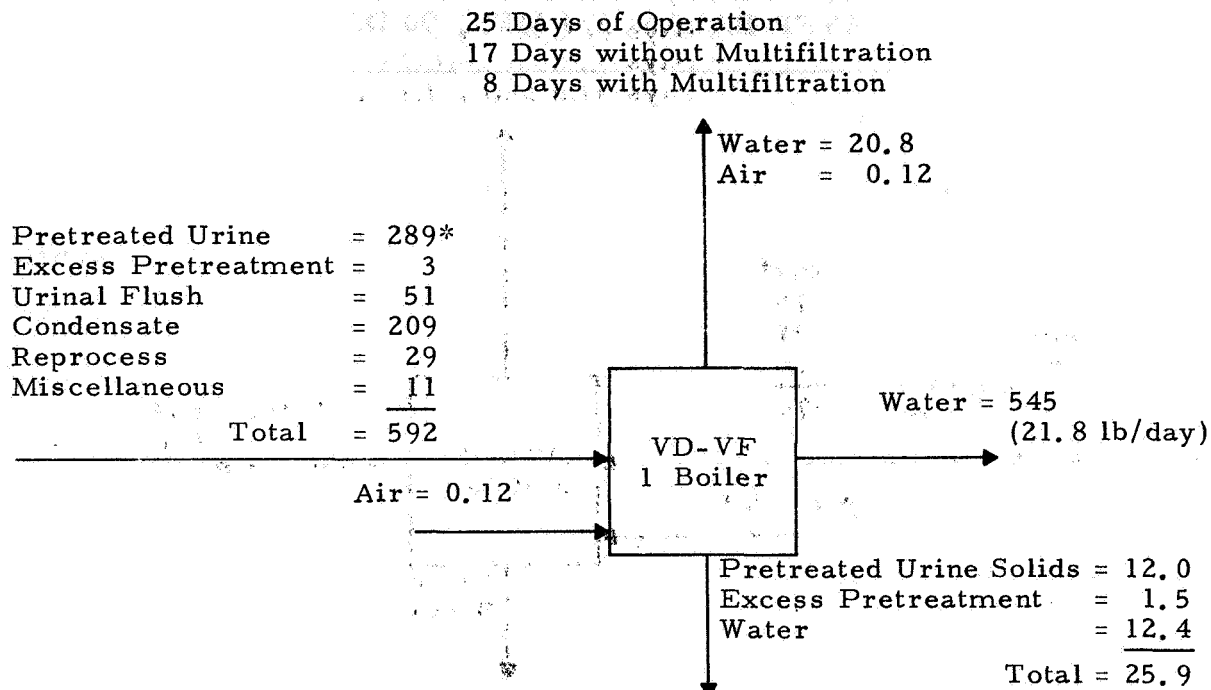
Table 1
POTABLE WATER SYSTEM PRETEST QUALIFICATION
MICROBIOLOGICAL DATA

Date	Raw Urine	MDAC Dispenser	VD-VF Condensate (B-84)	T1 (B-36)	T2 (B-38)	T3	T4	T5	T6	TB
5-2-70		$\frac{+}{0}$								
5-20-70			$\frac{0}{0}$							
5-21-70	$\frac{0}{6}$		$\frac{0}{0}$		$\frac{(1)}{299}$		$\frac{0}{0}$			
5-22-70			$\frac{0}{0}$		$\frac{0}{0}$		$\frac{0}{0}$			
5-27-70								$\frac{(2)}{16}$		
6-2-70				$\frac{0}{0}$		$\frac{0}{0}$			$\frac{0}{0}$	$\frac{0}{0}$
6-3-70			$\frac{0}{0}$			$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$		
6-9-70		$\frac{+}{0}$								
<p>KEY: $\frac{a}{d} \frac{b}{c}$ a = aerobes, No. /ml b = anaerobes, No. /ml c = fungi, No. /ml d = viruses, No. /ml</p> <p>(1) Pseudomonas, Klebsiella Aerobacter (2) Klebsiella Aerobacter, Staph. Epidermidis</p>										

Table 2
POTABLE WATER SUBSYSTEMS SUMMARY
WATER BALANCE 4 MEN, 90 DAYS

		<u>Pounds</u>	<u>Pounds</u>
Water Produced:			
Humidity control			2,676
VD-VF			1,353
Wick evaporator			680
Water Used:			
Consumed by crew		2,045	
Feed to solid amine		1,148	
Feed to VD-VF		644	
Wash water makeup and phase change		594	
Samples, inventory gain, losses, etc.		278	
		<u>4,709</u>	<u>4,709</u>
Source of Water Consumed:			
VD-VF		809	
Without post-filtration	450		
With post-filtration	<u>359</u>		
	809		
Wick evaporator		310	
Humidity condensate		926	
		<u>2,045</u>	

Table 3
VD-VF 1 BOILER MASS AND ENERGY BALANCE



Overall Water Recovery Efficiency ($\frac{\text{Water Out}}{\text{Water In}}$) = 94.3%

Expendables:

Pretreatment Solution	=	2.2
Boiler	=	54.4
Catalyst	=	4.0
MF Carbon	=	0.11
MF Resin	=	0.11
Antifoam	=	0.055
Air Bleed	=	0.121
Total	=	60.996

Isotope Heat:

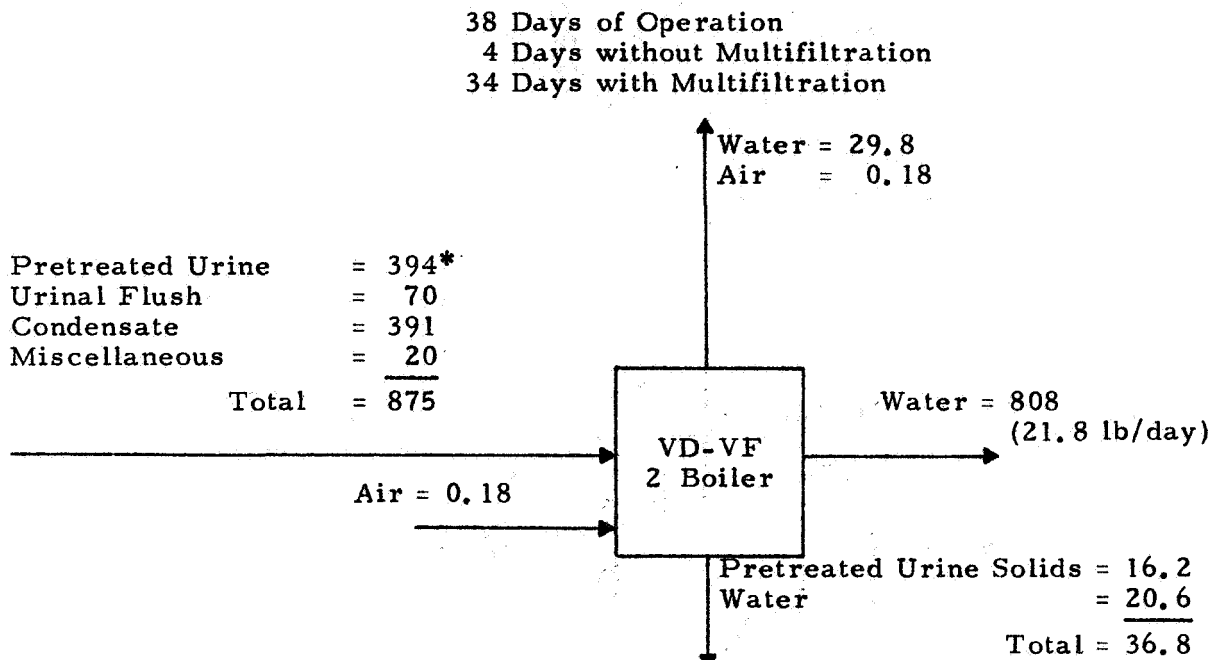
Boiler = 916.8 Btu/hr (268.5 watts)
Catalyst = 251.1 Btu/hr (73.54 watts)

Condenser Cooling (average) = 1,238 Btu/hr (362 watts)

Pumping Power (average) = 9 watts

*All weights in pounds

Table 4
VD-VF 2 BOILER MASS AND ENERGY BALANCE



Overall Recovery Efficiency ($\frac{\text{Water Out}}{\text{Water In}}$) = 94.1%

Expendables:

Pretreatment Solution	=	3.0
Boiler	=	57.5
Catalyst	=	4.0
MF Carbon	=	0.47
MF Resin	=	0.47
Antifoam	=	0.084
Air Bleed	=	0.184
Total	=	65.708

Isotope Heat:

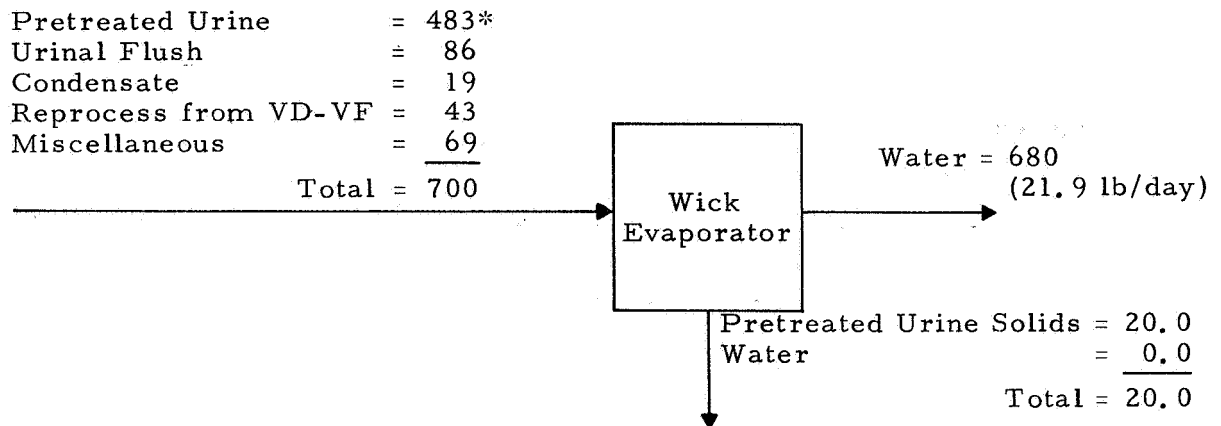
Boiler = 1004.6 Btu/hr (294.3 watts)
Catalyst = 163.2 Btu/hr (47.81 watts)

Condenser cooling (average) = 1,238 Btu/hr (362 watts)

Pumping power (average) = 9 watts

*All weights in pounds

Table 5
WICK EVAPORATOR MASS AND ENERGY BALANCE
31 DAYS OF OPERATION



Overall Recovery Efficiency $\left(\frac{\text{Water Out}}{\text{Water In}}\right) = 100\%$

Expendables:

Pretreatment Solution	=	3.7
Wicks	=	17.0
MF Carbon	=	0.44
MF Resin	=	0.44
Air Carbon {24 lb installed not expended }	=	---
Total	=	21.58

Heat (average) = 347 Btu/hr (101 watts)

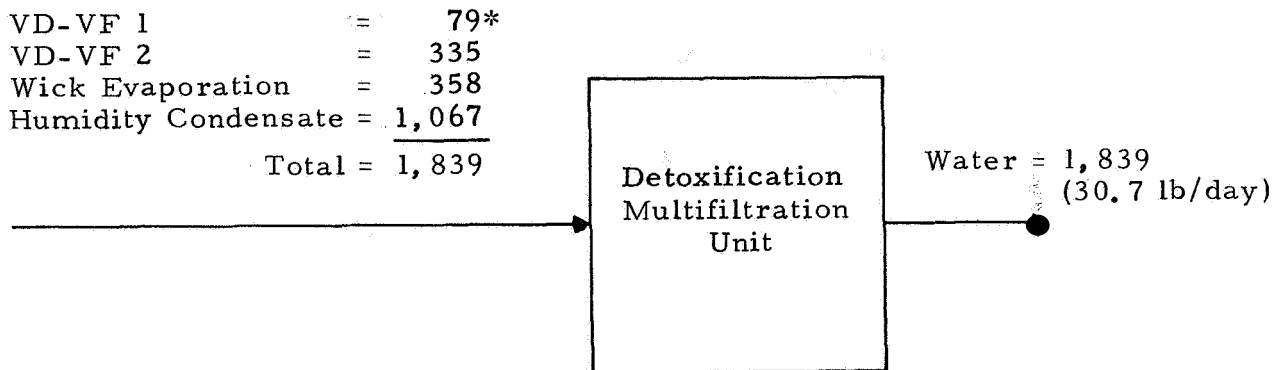
Condenser Cooling (average) = 360 Btu/hr (105 watts)

Blower power = 307 watts (includes humidity condensate)

Pumping power (average) = 0.7 watts

*All weights in pounds

Table 6
POTABLE WATER DETOXIFICATION MULTIFILTRATION
UNIT 60 DAYS OF OPERATION



Overall Water Recovery Efficiency $\left(\frac{\text{Water Out}}{\text{Water In}}\right) = 100\%$

Expendables:

Carbon	=	1.2
Resin	=	<u>1.2</u>
Total	=	2.4

Hold Tank Heating (T_1 and T_2): 556 Btu/hr (163 watts)

*All weights in pounds

TABLE 7.- POTABLE WATER SYSTEM

Date	Tank No.	Source	pH	Specific Conductivity ($\mu\text{mho-cm}^{-1}$)	TOC (mg/l)	NH ₃ (mg/l)	Color (Cobalt units)
			No std	No std	No std	1, pH>7 10, pH<7	15
6-9-70	3	W. Evap + dist H ₂ O	6.1	2.5	7	0	0
6-9-70	4	VD-VF + dist H ₂ O	6.4	5.0	5	0	5
6-16-70	6	VD-VF	5.1	38	7.7	1.4	1
6-18-70	5	VD-VF	4.9	18	5	0.6	0
6-19-70	5	VD-VF					
6-20-70	3	VD-VF	5.2	15	4	0.5	8
6-22-70	6	VD-VF	5.2	16	5	0.6	2
6-22-70	4	H. Cond. -MF	6.7	16	11	1.0	1
6-25-70	5	VD-VF	5.4	14	3.5	0.6	2
6-27-70	3	VD-VF + H. Cond. -MF	5.2	15	7	0.8	5
6-29-70	6	VD-VF + H. Cond. -MF	5.5	11	9	1.0	4
6-30-70	4	VD-VF					
7-1-70	4	Process T4 through MF	5.3	16	14	1.1	-
7-4-70	5	VD-VF-MF	5.7	10	17	1.4	3
7-5-70	3	VD-VF-MF	5.0	14	10	3.0	0
7-7-70	6	VD-VF-MF	4.8	17	12	2.9	1
7-11-70	5	W. Evap-MF	5.5	19	14	2.0	0
7-14-70	3	W. Evap-MF	4.7	19	15	2.1	-
7-15-70	6	W. Evap-MF	4.7	21	16	1.3	0
7-18-70	4	W. Evap + VD-VF-MF	4.9	18	12	0.5	0
7-22-70	5	VD-VF + H. Cond. -MF	4.8	13	8	0.6	1
7-23-70	6	VD-VF-MF	5.9	37	16	3.0	2
7-26-70	3	VD-VF-MF	6.6	34	9	3.1	1
7-30-70	4	W. Evap-MF	5.9	4.5	10	1.0	2
8-1-70	5	W. Evap-MF	5.7	7.5	12	1.0	2
8-3-70	6	W. Evap-MF	4.3	42	21	1.2	0
8-5-70	3	W. Evap-MF	4.3	48	27	1.4	0
Key:							
	TOC	=	Total Organic Carbon				
	MFM	=	Millipore Field Monitor				
	TNTC	=	Too numerous to count				
	*	=	Incorrect sampling technique				
	MF	=	Multifiltered				

CHEMICAL AND MICROBIOLOGICAL ANALYSES

Odor	Turbidity (Jackson units)	Taste	Foaming	48-hr MFM VD-VF condensate (No. /ml)	48-hr MFM tank (No. /ml)	Date Certi- fied
None objection- able	10	None objection- able	None persistent >15 sec	10	10	
Very slight	<5	Slight medicinal	0	0	0	6-11-70
Bland	0	Medicinal	0	0	0	6-11-70
Slight	0	Slight	0	0	0	6-18-70
Slight	0	Very slight	0	0	TNTC*	Retested
					0	6-21-70
Slight	<5	Slight	0	0	0	6-24-70
Slight	4	Slight	0	0	0	6-24-70
Slight	0	Flat	0	-	0	6-25-70
Slight	3	Slight	0	0	0	6-27-70
Slight medicinal	2	Medicinal	0	0.1	0	6-29-70
Slight medicinal	4	Medicinal	0	0	0	7-1-70
Objection- able		Objection- able		0.4	0	Rejected
-	2	Strongly medicinal	0	0	0	7-4-70
Slight medicinal	3	Slight medicinal	0	0	0	7-6-70
Slight	2	Slight medicinal	0	0	0	7-8-70
Slight	0	Slight	0	0.4	0	7-11-70
Slight	2	Slight	0	-	0	7-13-70
Slight	0	Slight	0	-	0	7-16-70
Slight	0	Flat	0	-	0	7-18-70
Flat	0	Flat	0	9.6	0	7-22-70
Flat	3	Flat	0	TNTC	0	7-24-70
Flat	3	Flat	0	7.6	0	7-27-70
Flat	3	-	0	300	0	7-29-70
Flat	3	Flat	0	-	0	8-1-70
Slight	4	Slight	0	-	0	8-4-70
Flat	0	Flat	0	-	0	8-5-70
Flat	0	Flat	0	-	0	8-8-70

TABLE 7.- POTABLE WATER SYSTEM

Date	Tank No.	Source	pH	Specific Conductivity ($\mu\text{mho-cm}^{-1}$)	TOC (mg/ l)	NH ₃ (mg/ l)	Color (Cobalt units)
			No std	No std	No std	1, pH>7 10, pH<7	15
8-7-70	4	W. Evap-MF	4.4	38	25	1.0	2
8-10-70	5	VD-VF-MF	4.2	44	28	1.8	0
8-13-70	6	VD-VF	7.0	31	9	2.8	0
8-16-70	3	VD-VF + H. Cond. -MF	4.2	42	33	1.0	0
8-18-70	4	VD-VF + H. Cond. -MF	6.7	15	10	1.3	0
8-20-70	5	VD-VF + H. Cond. -MF	5.5	15	10	1.2	1
8-24-70	6	VD-VF + H. Cond. -MF	4.3	38	23	1.4	-
8-27-70	3	VD-VF + H. Cond. -MF	4.3	32	21	2.2	2
8-30-70	4	VD-VF + H. Cond. -MF	4.3	29	20	1.7	0
9-1-70	5	VD-VF + H. Cond. -MF	4.6	22	18	2.2	0
9-4-70	6	W. Evap-MF	6.7	124	26	19.0	1
9-6-70	3	W. Evap-MF	6.5	15	7	2.5	1
9-9-70	4	W. Evap-MF	5.4	9	13	4.0	0

Key: TOC = Total Organic Carbon
 MFM = Millipore Field Monitor
 TNTC = Too numerous to count
 * = Incorrect sampling technique
 MF = Multifiltered

CHEMICAL AND MICROBIOLOGICAL ANALYSES (Concluded)

Odor	Turbidity (Jackson units)	Taste	Foaming	48-hr MFM VD-VF condensate (No. /ml)	48-hr MFM tank (No. /ml)	Date Certi- fied
None objection- able	10	None objection- able	None persistent >15 sec	10	10	
Slight	4	-	0	-	0	8-10-70
Slight	2	Slight	0	2.6	0	8-12-70
Bland	2	Bland	0	0.3	0	8-17-70
Bland	0	Bland	0	37.0	0	8-20-70
Bland	3	Bland	0	TNTC	0	8-20-70
Bland	2	Bland	0	TNTC	0	8-24-70
Bland	2	Bland	0	TNTC	0	8-27-70
Bland	4	Bland	0	TNTC	0	8-30-70
None	2	Bland	0	TNTC	0	9-2-70
Bland	2	Bland	0	0	0	9-5-70
Bland	3	-	0	-	0	Rejected
Bland	3	Bland	0	-	0	9-9-70
Bland	2	Bland	0	-	0	9-11-70

Table 8
POTABLE WATER SYSTEM MICROBIOLOGICAL DATA

Test Day	Date	T1	T2	T3	T4	T5	T6	Millipore Field Monitors, No. of Organisms per Ml				T7	T8	Wash Dispenser (Cold) 160° F		Viruses Apollo Dispenser (Cold) 160° F	
								VD-VF Cond. B84	MDAC Dispenser	Apollo Dispenser (Hot) 160° F	Apollo Dispenser (Cold) 50° F			Wash Dispenser (Cold) 160° F	Wash Dispenser (Cold) 160° F		
3	6-15-70	0						0	TNTC*	0	TNTC*						
4	6-16-70						0	0									
5	6-17-70							0									
6	6-18-70	210*				TNTC*		0									
7	6-19-70	7*				0		0									
8	6-20-70		3.5*	TNTC*	TNTC*			0		0		TNTC*	TNTC*				
9	6-21-70							0									
10	6-22-70			0	0		0	0									
11	6-23-70						0	4.2									0
12	6-24-70					0	0	0									
13	6-25-70							0									
14	6-26-70			0		0		0	170	0							
15	6-27-70							0.1									
16	6-28-70						0	0									
17	6-29-70						0	0				0.1	0				
18	6-30-70				0			0.4									
19	7-1-70				0			0									
20	7-2-70				0			0									
21	7-3-70				0			0									
22	7-4-70					0		0		0							
23	7-5-70			0				0									
24	7-6-70			0				0									
25	7-7-70							0.4		0							0
26	7-8-70						0	0									
28	7-10-70						0	0		0							
29	7-11-70					0											
31	7-13-70					0											
32	7-14-70			0													
34	7-16-70						0	0.2									
35	7-17-70						0	0.3									
36	7-18-70				0		0	9.6									
37	7-19-70							TNTC									
38	7-20-70				0			TNTC									
39	7-21-70							TNTC									0
40	7-22-70					0											
41	7-23-70						0	7.6									

Key: TNTC = Too numerous to count
* = Incorrect sampling procedure

Table 8
POTABLE WATER SYSTEM MICROBIOLOGICAL DATA (Continued)

Test Day	Date	T1	T2	T3	T4	T5	T6	Millipore Field Monitors, No. of Organisms per Ml					T7	T8	Wash		Viruses	
								VD-VF Cond. B84	MDAC Dispenser	Apollo Dispenser (Hot) 160°F	Apollo Dispenser (Cold) 50°F	Dispenser (Hot) 160°F			Dispenser (Cold) 100°F	Dispenser (Hot) 160°F	Dispenser (Cold) 160°F	
42	7-24-70					0	0	300			0							
43	7-25-70							100										
44	7-26-70			0			0	25.0							0		0	
45	7-27-70																	
47	7-29-70			0														
48	7-30-70				0						0							
50	8-1-70				0	0												
52	8-3-70					0	0											
53	8-4-70							10.7										0
54	8-5-70			0				0.1										
55	8-6-70							0										
56	8-7-70			0	0			0			0							
57	8-8-70							0										
58	8-9-70				0			0										
59	8-10-70					0		2.6										
60	8-11-70					0	0.6	0			0.1			0				
61	8-12-70							0										
62	8-13-70							0.3										
63	8-14-70						0	0										
64	8-15-70			0				37.0			0							
65	8-16-70							TNTC										
66	8-17-70			0.1				TNTC										
67	8-18-70				0			12.6							0.2		0.6	0
68	8-19-70				0			43.0										
69	8-20-70							TNTC										
70	8-21-70					0		TNTC			0							
71	8-22-70							TNTC										
72	8-23-70					0		TNTC										
73	8-24-70						0	TNTC										
74	8-25-70						0	490							0		0.3	
75	8-26-70							TNTC										
76	8-27-70			0				TNTC										
77	8-28-70							TNTC										
78	8-29-70			0				TNTC			0							
79	8-30-70				0			TNTC										
80	8-31-70				0			0										

Key: TNTC = Too numerous to count
* = Incorrect sampling procedure

Key: TNTC = Too numerous to count
* = Incorrect sampling procedure

Table 8
POTABLE WATER SYSTEM MICROBIOLOGICAL DATA (concluded)

Test Day	Date	T1	T2	T3	T4	T5	T6	Millipore Field Monitors, No. of Organisms per Ml								Viruses			
								VD-VF Cond. B84		MDAC Dispenser	Apollo Dispenser (Hot) 160°F		Apollo Dispenser (Cold) 50°F		T7	T8	Wash Dispenser (Hot) 160°F	Wash Dispenser (Cold) 100°F	Wash Dispenser (Hot) 160°F
81	9-1-70																		
82	9-2-70					0													
83	9-3-70					0													
84	9-4-70						0												
85	9-5-70						0						0						
86	9-6-70			0															
87	9-7-70			0															
88	9-8-70														0		0		
89	9-9-70				0														

Key: TNTC = Too numerous to count
* = Incorrect sampling procedure

Key: TNTC = Too numerous to count
* = Incorrect sampling procedure

Table 9
POTABLE WATER CHEMICAL PRETEST AND BIWEEKLY ANALYSIS

Date	Test Day	Tank No.	Source	Analysis Results (mg/l)							
				As	Ba	B	Cd	C1 ⁻	Cr	Cu	F
Standard				0.5	2.0	5.0	0.05	450	N.S.	3	2
5-25	-18	1	Distilled	<0.001	<1.0	<1.0	<0.02	13.5	<0.04	<0.001	0
5-25	-18	3	Distilled + wick evap M-F from Tank 2	<0.001	<1.0	<1.0	<0.02	15.2	<0.04	<0.001	0
5-25	-18	4	VD-VF, rejected*	<0.001	<1.0	<1.0	0.49*	21.3	0.2	0.11	0
5-25	-18	5	VD-VF, rejected*	<0.001	<1.0	<1.0	0.05*	9.6	0.2	0.005	0
5-25	-18	6	Distilled	<0.001	<1.0	<1.0	<0.02	30.2	<0.04	<0.001	0
5-25	-18	Backup	Iodine treated distilled	<0.001	<1.0	<1.0	<0.02	6.0	<0.04	<0.001	0
5-31	-12	Boiler 1	VD-VF				<0.05				
6-2	-10	Condensate Tank 1	VD-VF				<0.01				
6-3	-9	4	VD-VF	<0.05	<0.075	<0.075	<0.05	9.1	<0.075	<0.045	0.06
6-9	-3	Boiler 1	VD-VF	<0.07	<0.7	<7.0	0.008		0.08	0.03	
6-9	-3	Catalyst	VD-VF	<0.04	<0.4	<4.0	<0.005		0.006	0.04	
6-10	-2	Cold trap	VD-VF	<0.04	<0.7	16.0	3.5	22	1.0	0.6	
6-16	4	6	VD-VF				<0.05				
6-30	18	6	VD-VF	<0.03	<0.02	<0.3	0.009	0.41	0.01	0.009	
7-13	31	5	Wick evap + humidity condensate M-F	<0.03	<0.06	<0.3	0.0015	0	0.006	0.015	
7-15	35	2	Wick evap + humidity condensate M-F	<0.03	<0.07	<0.3	0.004	0	0.002	0.04	
7-21	39	Condensate Tank 1	VD-VF	<0.025	<0.1	<1.2	0.003	0	0.005	0.002	
7-28	46	6	VD-VF + humidity condensate M-F		<0.03	<1.5	0.0006	0	0.003	0.01	
8-11	60	5	VD-VF + humidity condensate M-F	<0.013	0.019	0.08	0.002	0	0.001	0.013	
8-25	74	6	VD-VF + humidity condensate M-F	<0.014	<0.093	0.09	0.002	0	0.002	0.031	
9-7	87	3	Wick evap + humidity condensate M-F					0			

*Incorrect sampling technique.

Table 9
POTABLE WATER CHEMICAL PRETEST AND BIWEEKLY ANALYSIS (Continued)

Date	Test Day	Tank No.	Source	Analysis Results (mg/l)							
				Pb	Se	Ag	SO ₄	TDS	NO ₃ As N	NO ₂ As N	Total N
Standard				0.2	0.05	0.5	250	1,000	N.S.	N.S.	10
5-25	-18	1	Distilled	<0.1	<0.05	0.0007	<1.0	146	<0.1	0.13	<0.23
5-25	-18	3	Distilled + wick evap M-F from Tank 2	<0.1	<0.02	0.0007	4.5	16	<0.1	0.13	<0.23
5-25	-18	4	VD-VF, rejected*	0.15		0.001	1.5		6.4	0.13	6.53
5-25	-18	5	VD-VF, rejected*	<0.1	<0.05	0.002	2.0		5.1	0.10	5.2
5-25	-18	6	Distilled	<0.1	<0.05	0.003	<1.0	16	<0.1	0.07	<0.17
5-25	-18	Backup	Iodine treated distilled	<0.1	<0.05	<0.0002	26.0	16	8.65	0.43	9.08
5-31	-12	Boiler 1	VD-VF								
6-2	-10	Condensate Tank 1	VD-VF								
6-3	-9	4	VD-VF	0.022	<0.05	<0.02	<0.5	156	0.55	0.38	0.93
6-9	-3	Boiler 1	VD-VF	<0.7	<0.7	0.03					
6-9	-3	Catalyst	VD-VF	<0.4	<0.4	0.001					
6-10	-2	Cold trap	VD-VF	0.46	<0.7	<0.03			1.2		
6-16	4	6	VD-VF								
6-30	18	6	VD-VF	0.01	<0.14	0.004		0	0.78	0.06	0.84
7-13	31	5	Wick evap + humidity condensate M-F		<0.075	0.004		5	1.0	0.004	1.004
7-15	35	2	Wick evap + humidity condensate M-F	<0.003	<0.08	0.005		0	<0.1	0.05	<0.15
7-21	39	Condensate Tank 1	VD-VF	<0.002	<0.25	0.006		0	<0.1	0.035	<0.135
7-28	46	6	VD-VF + humidity condensate M-F	<0.006	<0.3	0.003		0	<0.1	0.1	<0.2
8-11	60	5	VD-VF + humidity condensate M-F	0.006	<0.013	0.011		0	0	0.03	0.03
8-25	74	6	VD-VF + humidity condensate M-F	0.005	0.013	0.004		10.0	0	0.003	0.003
9-7	87	3	Wick evap + humidity condensate M-F					28.0	0	0.008	0.008

*Incorrect sampling technique.

Table 9

POTABLE WATER CHEMICAL PRETEST AND BIWEEKLY ANALYSIS (Continued)

Date	Test Day	Tank No.	Source	Analysis Results (mg/l)							
				A1	Be	Bi	Ca	Co	Fe	Li	Mg
Standard				N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
5-25	-18	1	Distilled		<0.002	<1.0	0.004	<0.01	<0.002	<0.001	0.02
5-25	-18	3	Distilled + wick evap M-F from Tank 2		<0.002	<1.0	0.05	<0.01	<0.002	<0.001	0.14
5-25	-18	4	VD-VF, rejected*	0.53	<0.002	<1.0	0.03	<0.01	1.75	0.001	0.04
5-25	-18	5	VD-VF, rejected*	0.47	<0.002	<1.0	0.02	<0.01	1.5	<0.001	0.02
5-25	-18	6	Distilled		<0.002	<1.0	0.008	<0.01	<0.002	<0.001	0.02
5-25	-18	Backup	Iodine treated distilled		<0.002	<1.0	0.008	<0.01	<0.002	<0.001	0.02
5-31	-12	Boiler 1	VD-VF						0.1		
6-2	-10	Condensate Tank 1	VD-VF								
6-3	-9	4	VD-VF	0.038	<0.0001	<0.038	0.18	<0.002	<0.38	<0.0075	0.045
6-9	-3	Boiler 1	VD-VF	0.07	<0.03	0.02	0.1	<0.03	0.1	<0.0007	0.05
6-9	-3	Catalyst	VD-VF	4.0	<0.02	<0.008	0.3	<0.02	0.04	0.001	0.07
6-10	-2	Cold trap	VD-VF	1.3	<0.0007	<0.006	0.8	0.03	12	0.001	0.3
6-16	4	6	VD-VF								
6-30	18	6	VD-VF								
7-13	31	5	Wick evap + humidity condensate M-F	1.7	<0.0003	0.002	0.3	<0.002	0.08	0.0002	<0.06
7-15	35	2	Wick evap + humidity condensate M-F	0.05	<0.0003	0.004	0.04	<0.002	0.03	<0.0002	0.02
7-21	39	Condensate Tank 1	VD-VF	0.01	<0.005	<0.003	0.054	<0.006	0.014	0.00008	0.008
7-28	46	6	VD-VF + humidity condensate M-F		<0.005				0.044		
8-11	60	5	VD-VF + humidity condensate M-F		0.0001						
8-25	74	6	VD-VF + humidity condensate M-F								
9-7	87	3	Wick evap + humidity condensate M-F								

*Incorrect sampling technique.

Table 9
POTABLE WATER CHEMICAL PRETEST AND BIWEEKLY ANALYSIS (Concluded)

Date	Test Day	Tank No.	Source	Analysis Results (mg/l)								
				Mn	Hg	Ni	K	Si	Na	Sn	Zn	Mo
Standard				N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
5-25	-18	1	Distilled	<0.01	<0.1	<0.05	0.02	0.3	0.22	<0.25	<0.01	<0.01
5-25	-18	3	Distilled + wick evap M-F from Tank 2	<0.1	<0.01	<0.05	0.64	1.0	0.38	<0.25	<0.014	<0.01
5-25	-18	4	VD-VF, rejected*	0.16	<0.1	0.9	0.03	0.8	0.43	<0.25	0.27	<0.01
5-25	-18	5	VD-VF, rejected*	0.62	<0.1	0.9	0.04	<0.03	0.19	<0.25	0.24	<0.01
5-25	-18	6	Distilled	<0.01	<0.1	<0.05	0.01	0.3	0.3	<0.25	<0.01	<0.01
5-25	-18	Backup	Iodine treated distilled	0.08	<0.1	<0.05	1.2	<0.03	0.3	<0.25	0.024	<0.01
5-31	-12	Boiler 1	VD-VF									
6-2	-10	Condensate Tank 1	VD-VF									
6-3	-9	4	VD-VF	<0.075	<0.038	0.38	<0.038	0.2	<0.075	0.02	0.08	0.003
6-9	-3	Boiler 1	VD-VF	1.8	<1.5	1.3	0.03	0.2	0.2	0.07	0.02	<0.02
6-9	-3	Catalyst	VD-VF	0.1	<0.75	0.01	0.08	0.1	1.0	0.08	0.03	<0.01
6-10	-2	Cold trap	VD-VF	0.5	<0.2	2.2	24	0.5	1.2	<0.4	0.8	0.03
6-16	4	6	VD-VF									
6-30	18	6	VD-VF									
7-13	31	5	Wick evap + humidity condensate M-F	0.004	<0.075	0.05	0.21		0.2			
7-15	35	2	Wick evap + humidity condensate M-F	0.13	<0.08	0.37	0.04	0.12	0.05	<0.02	0.009	0.008
7-21	39	Condensate Tank 1	VD-VF	0.0044	<0.04	0.003	0.025	<0.04	0.13	<0.01	0.012	<0.004
7-28	46	6	VD-VF + humidity condensate M-F									
8-11	60	5	VD-VF + humidity condensate M-F									
8-25	74	6	VD-VF + humidity condensate M-F									
9-7	87	3	Wick evap + humidity condensate M-F									

*Incorrect sampling technique.

Table 10

DATA ON IODINE DISSIPATION IN BACKUP
POTABLE WATER STORAGE TANK DURING 90-DAY
SPACE STATION SIMULATOR TEST

Tank Design

Type: Cylinder with flat ends
 Size: 15-in. diameter x 66 in. - 14-gage shell, 12-gage ends
 Material: Type 304 S/S-2B
 Quantity: 400 lb (50 gal)

Water Chemistry

Source: Sparkletts distilled drinking water. Specific conductivity
 ≈ 3 to $5 \mu\text{mho-cm}^{-1}$
 Treatment: Add iodine solution
 (40 g I_2 + 52 g KI + 1,000 g H_2O) to reach 6 ppm/ I_2 as
 measured by the silver method. No additional solution added.

 I_2 Dissipation Data

<u>Date</u>	<u>Storage Day No.</u>	<u>I_2 Content (ppm)</u>	<u>Millipore Field Monitor No. /ml</u>	<u>Comment</u>
5-22-70	1	6		Filled tank
5-25	4	5		
6-2	12	5	0	
6-8	18	5		
6-13	23	--		Start 90-day SSS test
6-22	32	1*		
6-30	40	1*		
7-6	46	1*		
7-13	53	0.5*		
7-13	53	0.5*		

*Incorrect sampling procedure

Table 10
DATA ON IODINE DISSIPATION IN BACKUP
POTABLE WATER STORAGE TANK DURING 90-DAY
SPACE STATION SIMULATOR TEST (Concluded)

<u>I₂ Dissipation Data (continued)</u>				
<u>Date</u>	<u>Storage Day No.</u>	<u>I₂ Content (ppm)</u>	<u>Millipore Field Monitor No./ ml</u>	<u>Comment</u>
7-21-70	61	4.5		
7-21	61	5.0		
7-28	68	4.5		
8-4	75	5.0	0	
8-11	82	5.0	0	
8-18	89	5.0	0	
8-25	96	5.0		
9-1	103	5.0		
9-8	110	5.0		
9-10	112	---		End 90-day SSS test
9-24	126	5.0		Emptied tank

Table 11
WASH WATER SYSTEM SUMMARY
WATER BALANCE AND EXPENDABLES 4 MEN, 90 DAYS

	<u>Pounds</u>	<u>Pounds</u>
Water Produced:		
Multifiltration unit		11,182
Water Used:		
Washing { Including evaporation loss = 560 lb }	10,448	
Reprocess	500	
Urinal flush	207	
Phase change	88	
Miscellaneous	13	
Inventory change	-74	
	<u>11,182</u>	<u>11,182</u>
Expendables:		
Four carbon columns	12	
Two resin columns	6	
Four particulate filters	2	
Cleansing agent (Basic H)	4	
Total expendables	<u>24</u>	
Heat:		
Tank heaters:	817 Btu/hr (239 watts) average	
Power:		
Pump:	1,056 watts for 4.32 hours total operating time	

Table 12
WASH WATER CHEMICAL, PHYSICAL AND MICROBIAL ANALYSIS

Date	Test Day	Tank No.	Turbidity (ppm SiO ₂)	Color (Cobalt Units)	Odor	Foaming	pH	Specific Conductivity (μmho-cm ⁻¹)	TOC (mg/l)	TDS (mg/l)	Millipore Field Monitor-48-Hour Count (No./ml)	
											Hot (160°F)	Cold (100°F)
6-22	10	7	80		Flat	None	6.4	28	81	135		
6-22		8	123		Slight	None	6.7	92	164	428		
6-30	18	7	3	4	Slight	None	3.5	250	152	81	1	
6-30		8	55	Cloudy	Slight	None	3.7	280	190	216	0	
7-6	24	7	2		Flat	None	3.8	130	99	31		
7-6		8	35		Slight	None	4.0	180	162	469		
7-13	31	7	0		Flat	None	3.4	510	174	102		
7-13		8	16	2	Slight	None	3.3	490	174	219		
7-21	39	7	0	0	Rubber	None	7.6	330	90	273		
7-21		8	112	Cloudy	Rubber	None	7.0	380	231	579		
7-28	46	7	0	2	Flat	None	3.7	990	250	214	0	0
7-28		8	105	Cloudy	Slight	None	3.8	1,000	260	494		
8-4	53	7	3	2	Slight	None	7.4	102	82	62		
8-4		8	83	Cloudy	Slight	Slight	7.2	740	263	484		
8-11	60	7	2	0	Slight	None	3.2	300	112	86	1	0
8-11		8	78	Cloudy	Slight	Slight	3.3	285	177	726		
8-18	67	7	2	0	Bland	None	3.4	310	151	191	2	6
8-18		8	170	Cloudy	Slight	Slight	3.8	335	258	669		
8-25	74	7			Slight	None	3.2	745	233	224	0	3
8-25		8			Slight	Slight	3.5	645	275	514		
9-1	81	7	2		Slight	None	3.0	1,240	340	1,366	0	0
9-1		8	130	Cloudy	Slight	Slight	3.0	1,110	429	1,710		
9-8	88	7	2		Slight	None	3.9	1,470	275	1,088	0	0
9-8		8	93	Cloudy	Slight	Slight	4.0	1,660	300	1,500		

Table 13
POTABLE AND WASH WATER SYSTEMS
POWER CONSUMPTION

	Kilowatt-hours	Average Watts During Operation
Potable Water System		
Holding Tank 1	192	89
Holding Tank 2	158	74
Use Tank 3	180	83
Use Tank 4	161	75
Use Tank 5 + Circulation pump	286	133
Use Tank 6	206	96
Humidity condensate pump, 67-hour operation	7	104
Wick Evaporator heater, 1, 127-hour operation	374	332
110-v Subtotal =	1,564	986
Humidity control blower, 400 Hz	661	307
Total =	2,225	1,293
Wash Water System		
Use Tank 7	244	113
Process Tank 8	271	126
Sink pump, 4.32-hour operation	5	1,056
Washer, 4-hour operation	4	1,000
Dryer, 44-hour operation	82	1,865
Total =	606	4,160

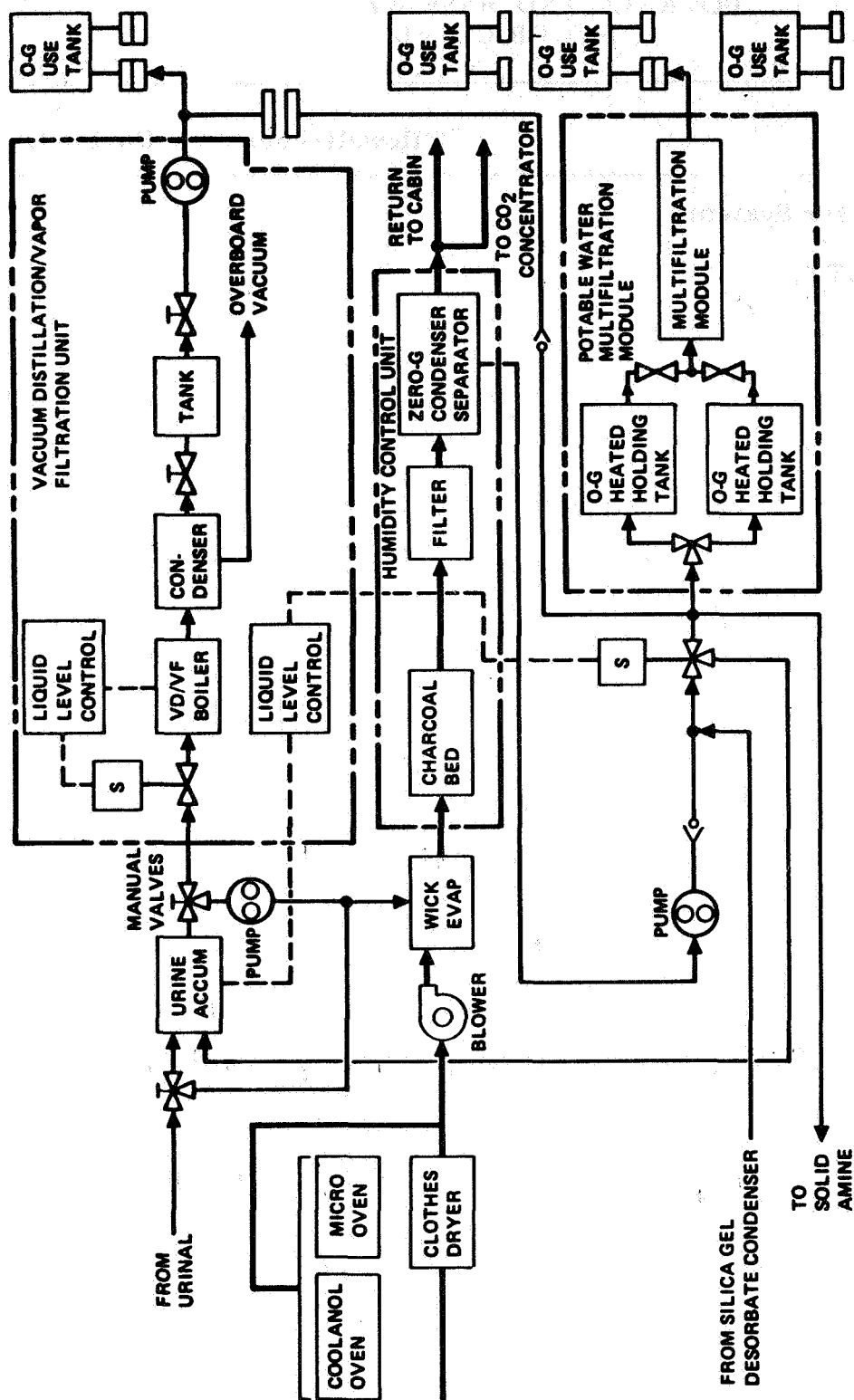


Figure 1.- Potable water subsystem.

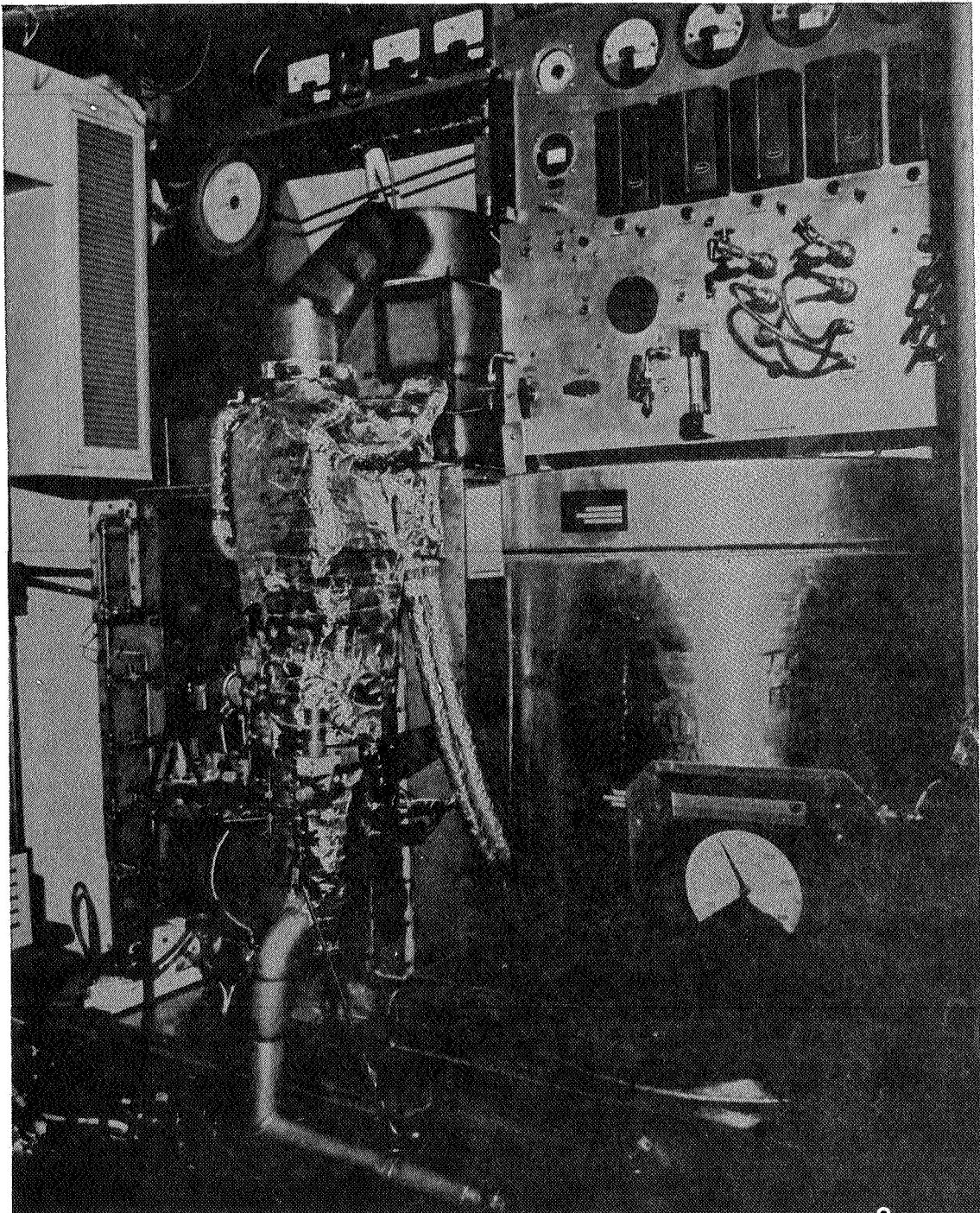


Figure 2.- Potable water recovery unit.

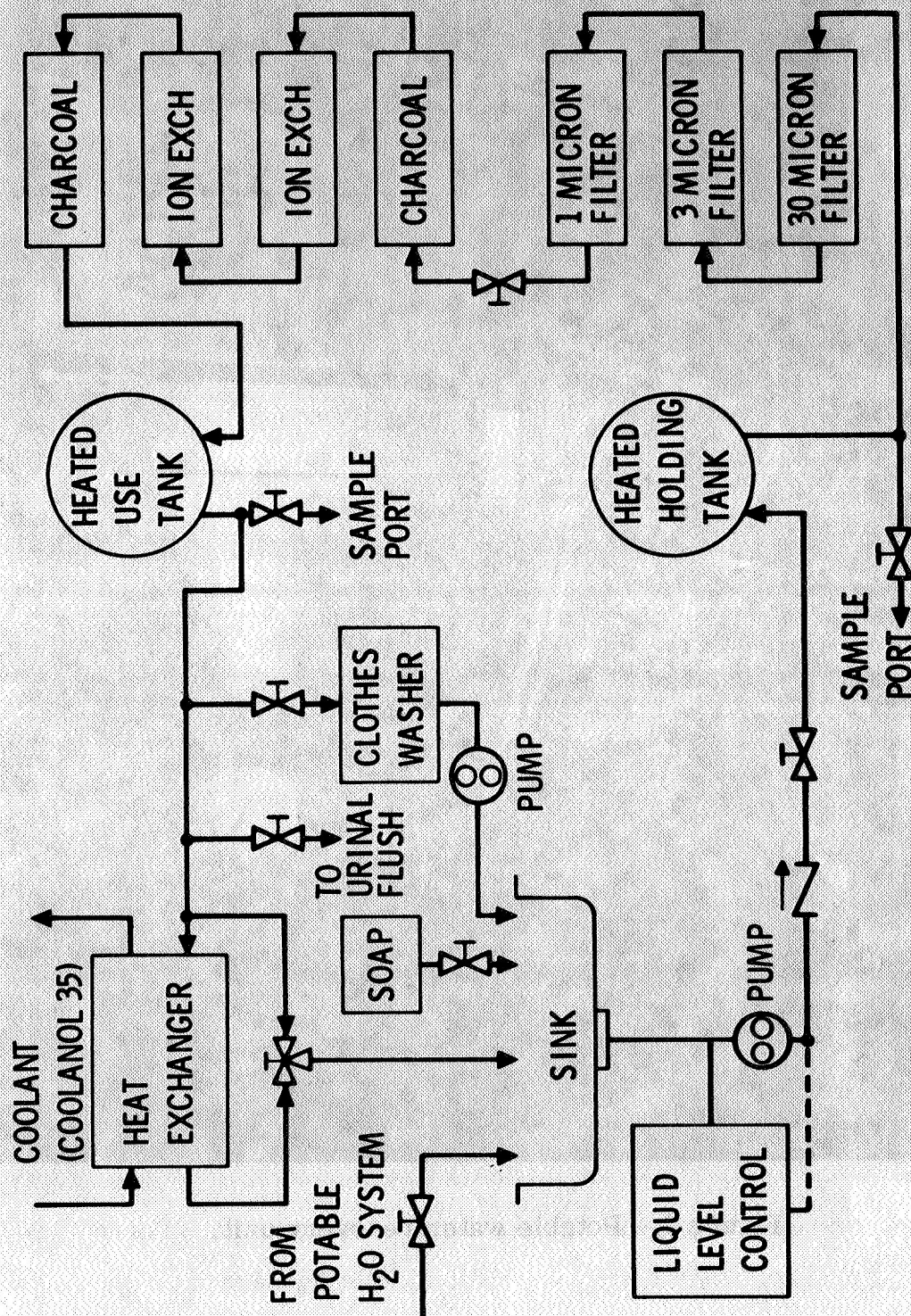


Figure 3.- Wash water recovery unit.

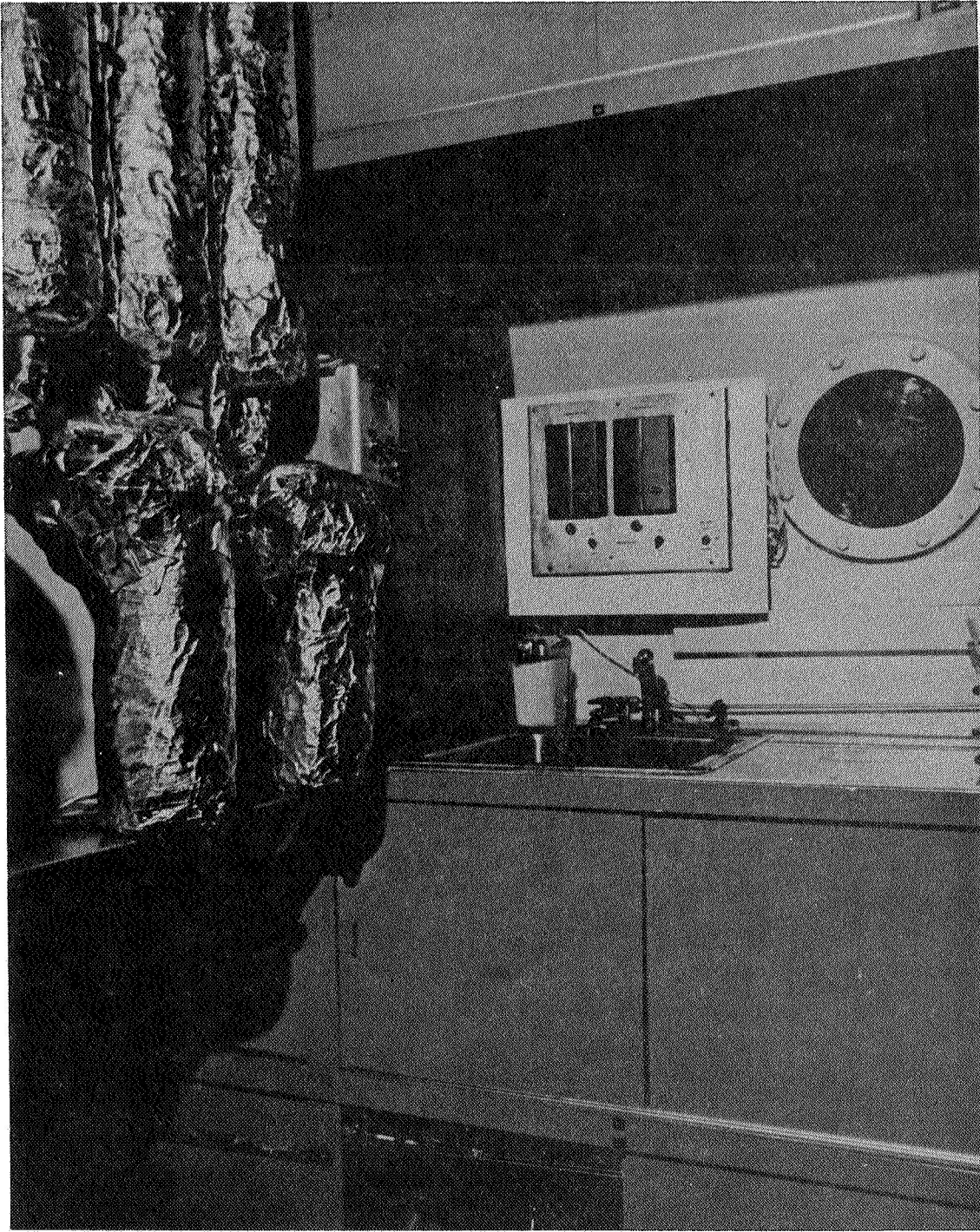


Figure 4.- Wash water subsystem filters and sink.

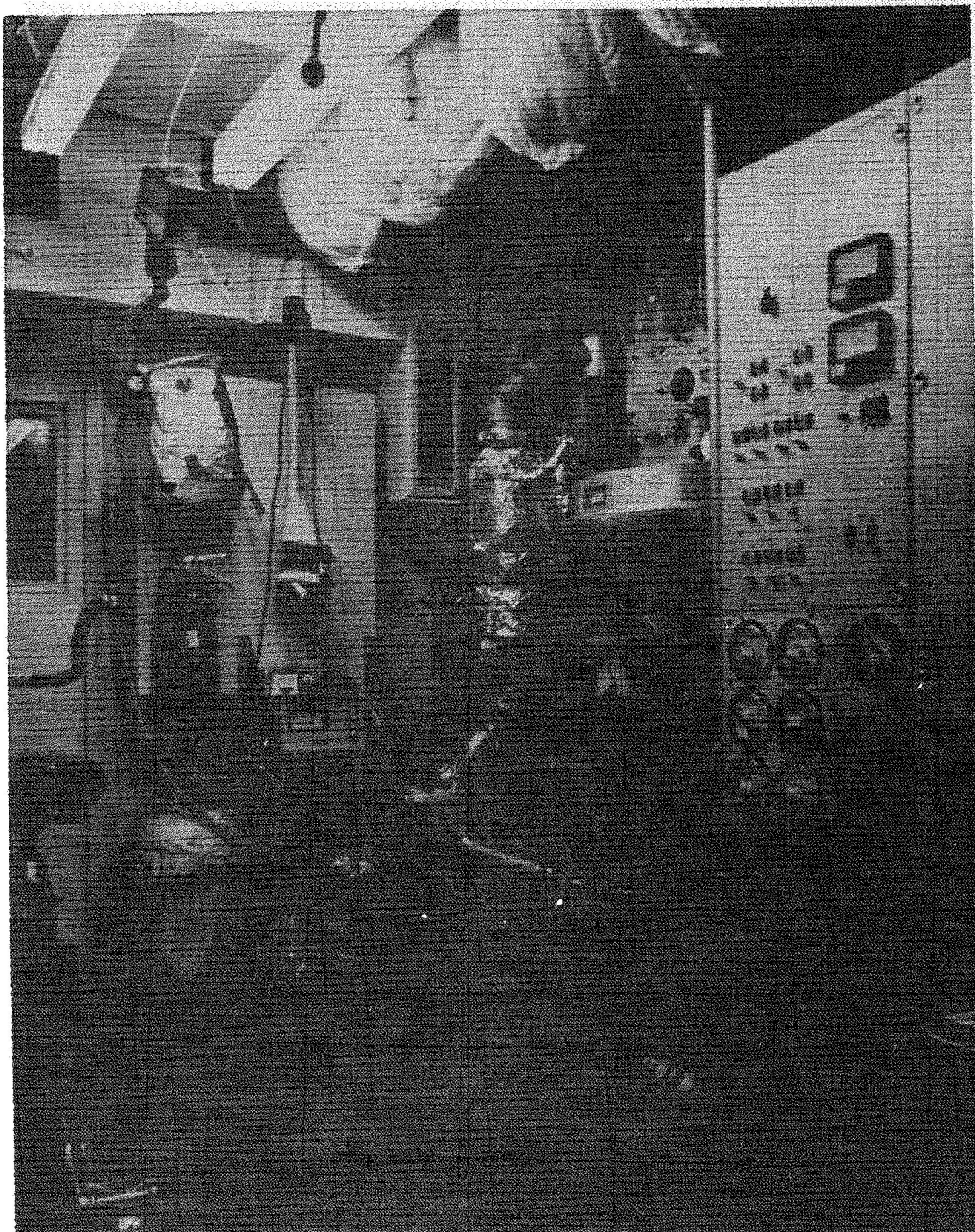


Figure 5.- Potable water recovery units and water storage.

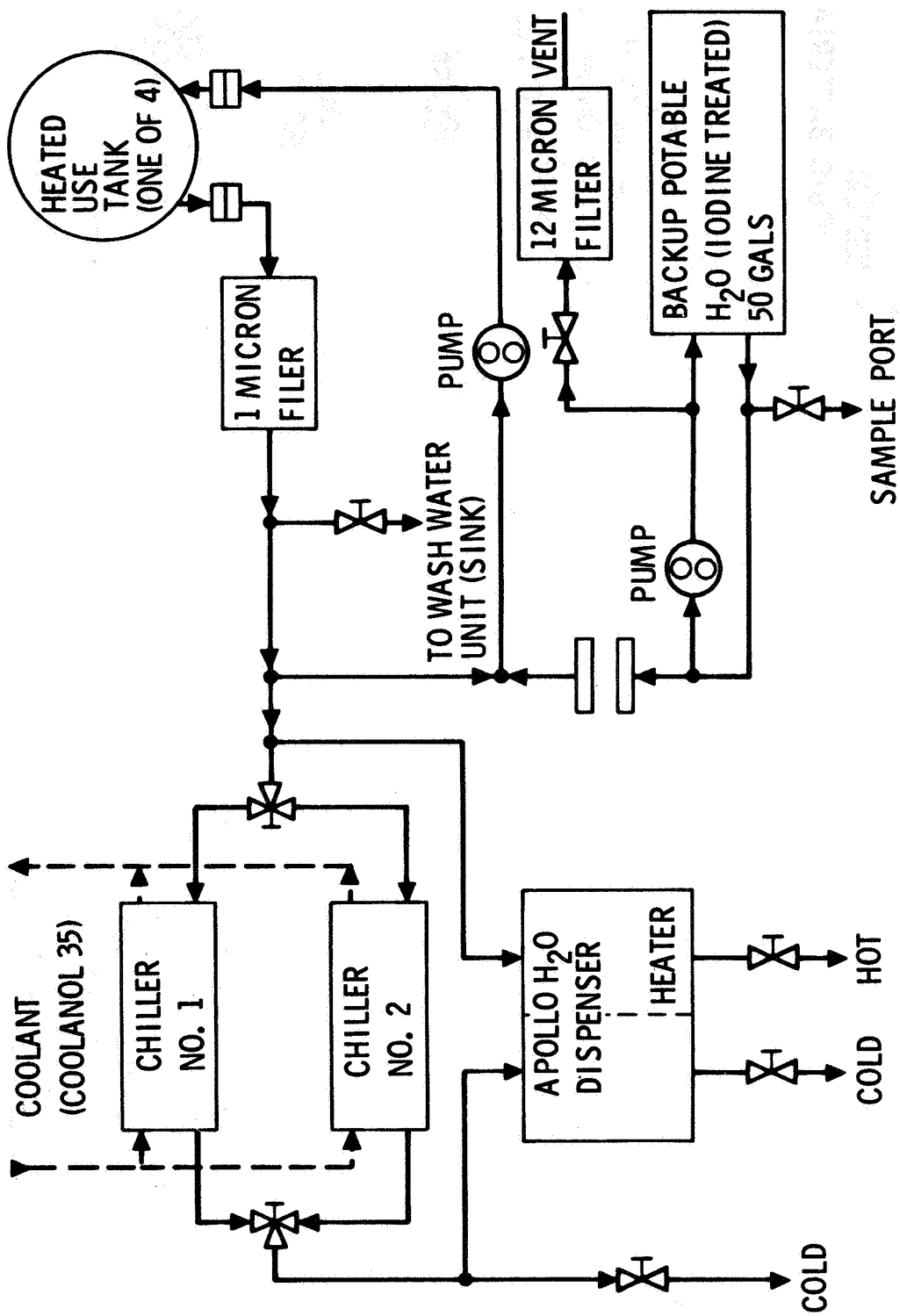


Figure 6.- Potable water distribution system.

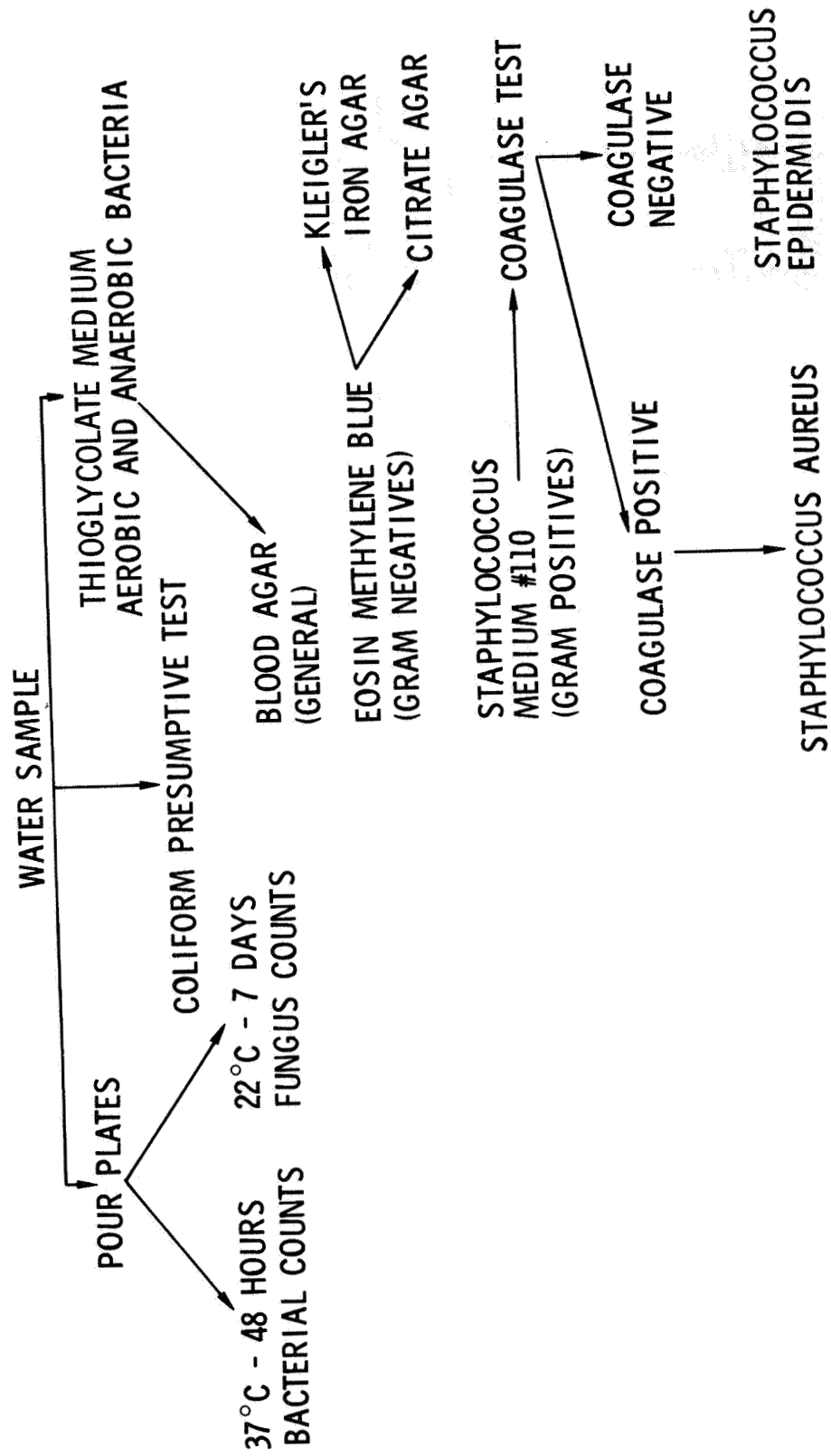


Figure 7.- Procedure for subculturing microorganisms.

EOSIN METHYLENE BLUE AGAR

	LACTOSE POSITIVE		LACTOSE NEGATIVE		
	KLEIGLER'S IRON AGAR	CITRATE		KLEIGLER'S IRON AGAR	CITRATE
ESCHERICHIA COLI	A/AG	O	PSEUDOMONAS	ALK/NC	+
ESCHERICHIA FREUNDII	A/AG	V	PARACOLO- BACTERIUM	ALK/AG	O
KLEBSIELLA-AEROBACTER	A/AG	+	PROTEUS SPECIES	ALK/AG	V, O, + (DEPENDING ON SPECIES)
INTERMEDIATE COLIFORMS	A/AG	+	SALMONELLA	ALK/AG	V
			SHIGELLA	ALK/A	O
			ALCALIGENES	ALK/NC	+

KEY:

ALK : ALKALINE REACTION	+	: POSITIVE REACTION
NC : NO CHANGE IN INDICATOR	O	: NEGATIVE REACTION
A : ACID REACTION	V	: VARIABLE REACTION

Figure 8.- Gram negative organisms.

TO: Dr. P. Mader

FROM: Medical Director 90-Day Run

SUBJECT: CHEMICAL AND PHYSICAL WATER ANALYSIS

ACTION: Perform the analyses checked below

Source of Water: ☐ VD-VF
☐ Humidity Condensate
☐ Air Evaporation

Actual Sample Size _____ mL
 Total plate count – 24 Hr _____ per mL
 – 48 Hr _____ per mL

Date of Sample _____

Location of Sample _____

Sample Number _____

☐ Certified to use.

Signed: _____
 Medical Director Date

		Amount	Standard
MEASURED EVERY TANK	<input type="checkbox"/> Turbidity	_____	(10) Jackson Units
	<input type="checkbox"/> Color	_____	(15) Pt-Co Units
	<input type="checkbox"/> Taste	_____	(none objectionable)
	<input type="checkbox"/> Odor	_____	(none objectionable)
	<input type="checkbox"/> Foaming	_____	(none persistent >15 sec)
	<input type="checkbox"/> pH	_____	(no std)
<input type="checkbox"/> K	_____	(no std) $\mu\text{mho-cm}^{-1}$	

		Amount	Standard
MEASURED EVERY 2 WEEKS	<input type="checkbox"/> As	_____	(0.5) mg/L
	<input type="checkbox"/> Ba	_____	(2) mg/L
	<input type="checkbox"/> B	_____	(5) mg/L
	<input type="checkbox"/> Cd	_____	(0.05) mg/L
	<input type="checkbox"/> Cl ⁻	_____	(450) mg/L
	<input type="checkbox"/> Cr	_____	(no std) mg/L
	<input type="checkbox"/> Cu	_____	(3) mg/L
	<input type="checkbox"/> F	_____	(2) mg/L

		Amount	Standard
MEASURED TO INITIALLY QUALIFY SYSTEM PRIOR TO START OF 90-DAY TEST	<input type="checkbox"/> Al	_____	(no std) mg/L
	<input type="checkbox"/> Be	_____	(no std) mg/L
	<input type="checkbox"/> Bi	_____	(no std) mg/L
	<input type="checkbox"/> Ca	_____	(no std) mg/L
	<input type="checkbox"/> Co	_____	(no std) mg/L
	<input type="checkbox"/> Fe	_____	(no std) mg/L
	<input type="checkbox"/> Li	_____	(no std) mg/L
	<input type="checkbox"/> Mg	_____	(no std) mg/L
	<input type="checkbox"/> Mn	_____	(no std) mg/L
	<input type="checkbox"/> Hg	_____	(no std) mg/L
	<input type="checkbox"/> Ni	_____	(no std) mg/L
	<input type="checkbox"/> K	_____	(no std) mg/L

	Amount	Standard
<input type="checkbox"/> NH ₃	_____	1, pH >7 10, pH <7 mg/L
<input type="checkbox"/> TOC	_____	(no std) mg/L
<input type="checkbox"/> COD	_____	(100) mg/L
<input type="checkbox"/> Br	_____	(1) mg/L
<input type="checkbox"/> Cr ⁺⁶	_____	(0.05) mg/L

	Amount	Standard
<input type="checkbox"/> Pb	_____	(0.2) mg/L
<input type="checkbox"/> Se	_____	(0.05) mg/L
<input type="checkbox"/> Ag	_____	(0.5) mg/L
<input type="checkbox"/> SO ₄ ⁼	_____	(250) mg/L
<input type="checkbox"/> TDS	_____	(1,000) mg/L
<input type="checkbox"/> NO ₃ as N	_____	(no std) mg/L
<input type="checkbox"/> NO ₂ as N	_____	(no std) mg/L
<input type="checkbox"/> Total NO ₃ and NO ₂ as N	_____	(10) mg/L

	Amount	Standard
<input type="checkbox"/> Si	_____	(no std) mg/L
<input type="checkbox"/> Na	_____	(no std) mg/L
<input type="checkbox"/> Sn	_____	(no std) mg/L
<input type="checkbox"/> Zn	_____	(no std) mg/L
<input type="checkbox"/> P	_____	(no std) mg/L
<input type="checkbox"/> Mo	_____	(no std) mg/L

Figure 9.- Checkoff sheet.

(21) O

TANK NO. 3

FIG. 8 O

	MO	DAY	HOUR	SIGNED
START FILL 9 LB.	7	25	2210	GU
END FILL 80 LB	7	26	0200	ECT
SAMPLES TAKEN	7	26	1400	R. malin
CERTIFIED: YES <input checked="" type="checkbox"/>	7	29	0500	Shen
START USE 80	7	31	2200	JSH
AMT IN TANK: 49	8	1	2315	JSH
AMT IN TANK: 23	8	2	2330	JSH
AMT IN TANK: 9	8	3	2359	JSH
AMT IN TANK:				
AMT IN TANK:				
END USE 8	8	3	0100	ECT
CERTIFIED: NO <input type="checkbox"/>				
REPROCESSED				
EMPTY, READY FOR REFILL	8	3		ECT

pH 6.55 COLOR 1

K 34 ODOR FLAT

TOC 9 TURBIDITY 3

NH₃ 3.1 TASTE =

~~Ag+~~ = FOAMING NONE

TPC NEG.

HEAT: YES ☒ NO ☐

IODINE: YES ☐ NO ☒

~~Ag+ GEN:~~ YES ☐ NO ☐

SOURCE: VD-VF

VIA TANK 1

M/F

Figure 10.- Potable water tank status card.

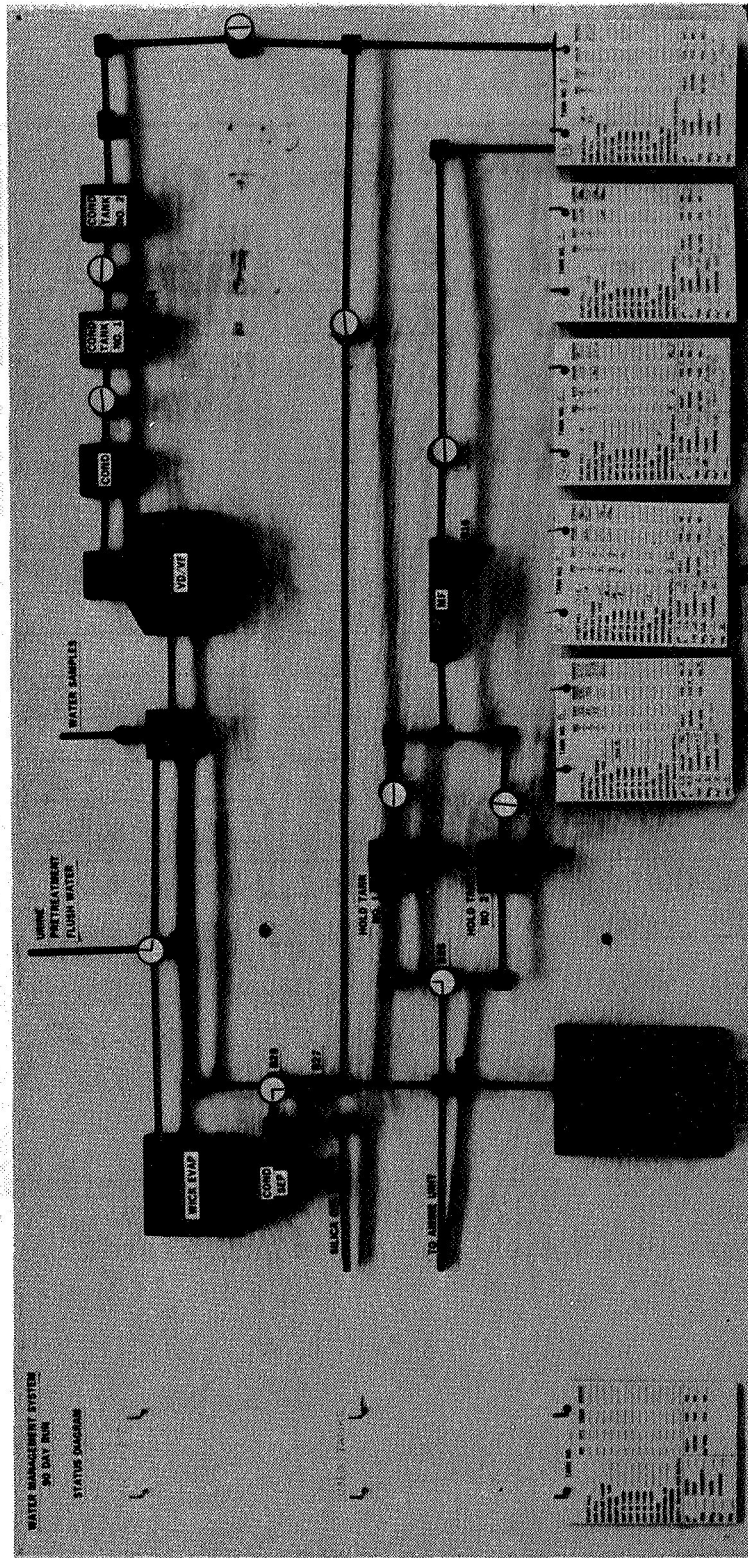


Figure 11.- Water management system.



Figure 12.- VD/VF expended boiler.

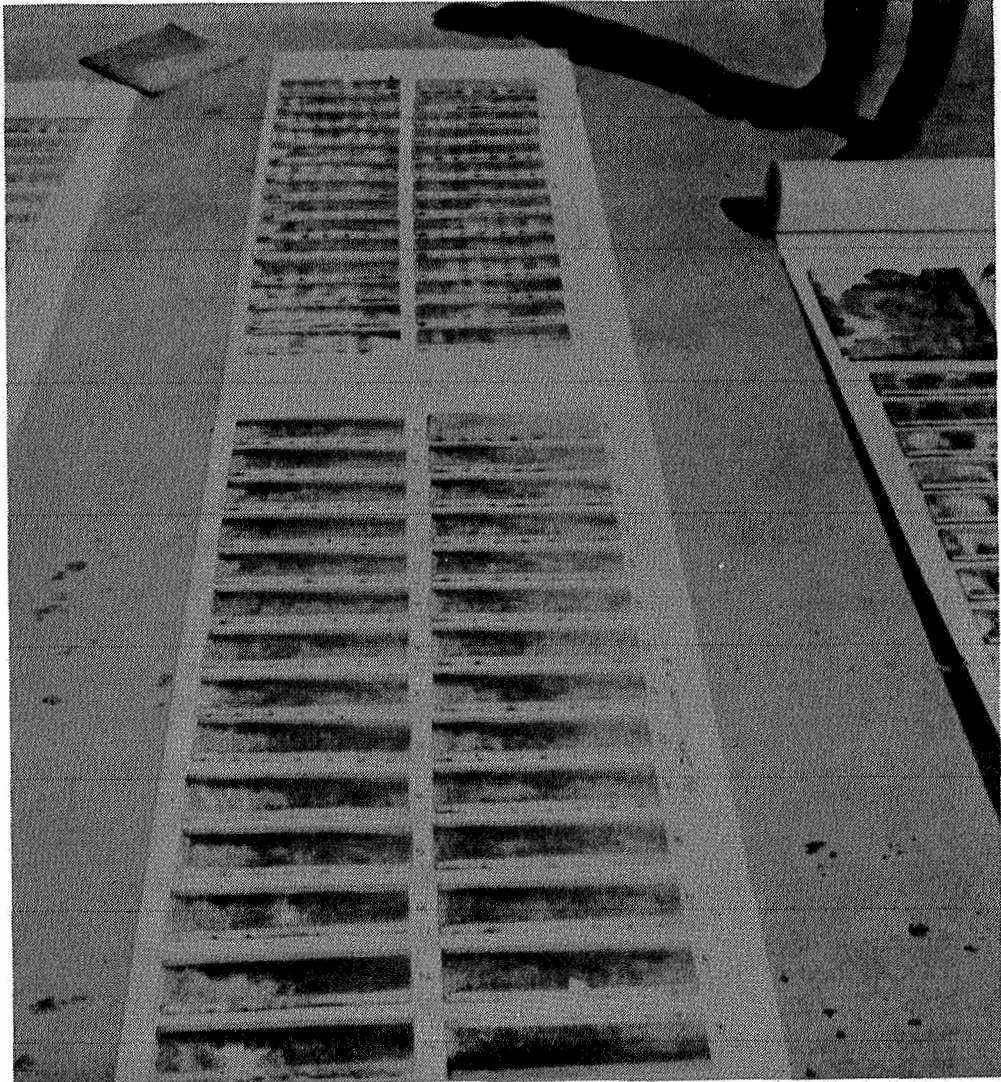


Figure 13.- Expended wicks.

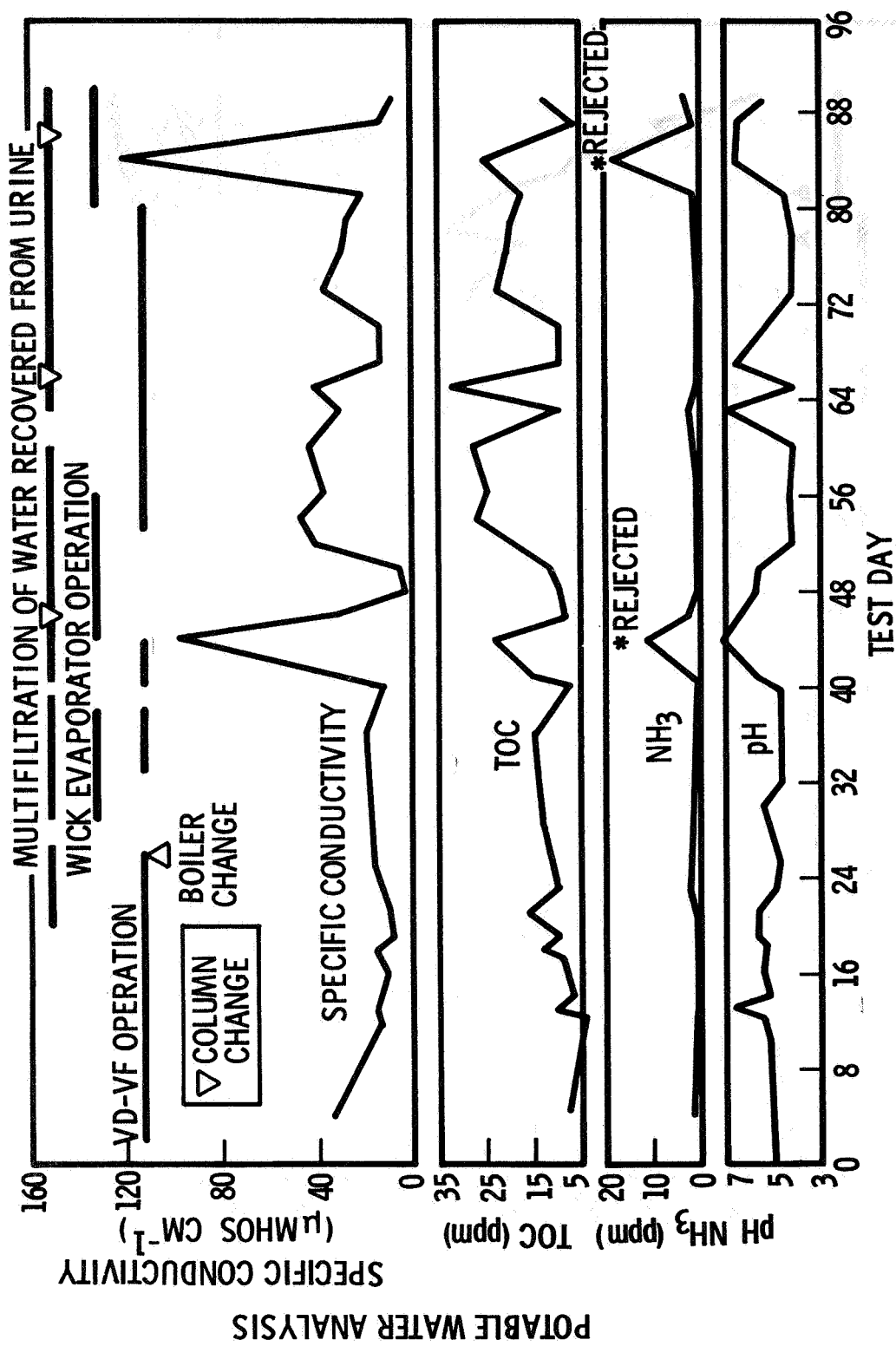


Figure 14.- Reclaimed potable water analysis.

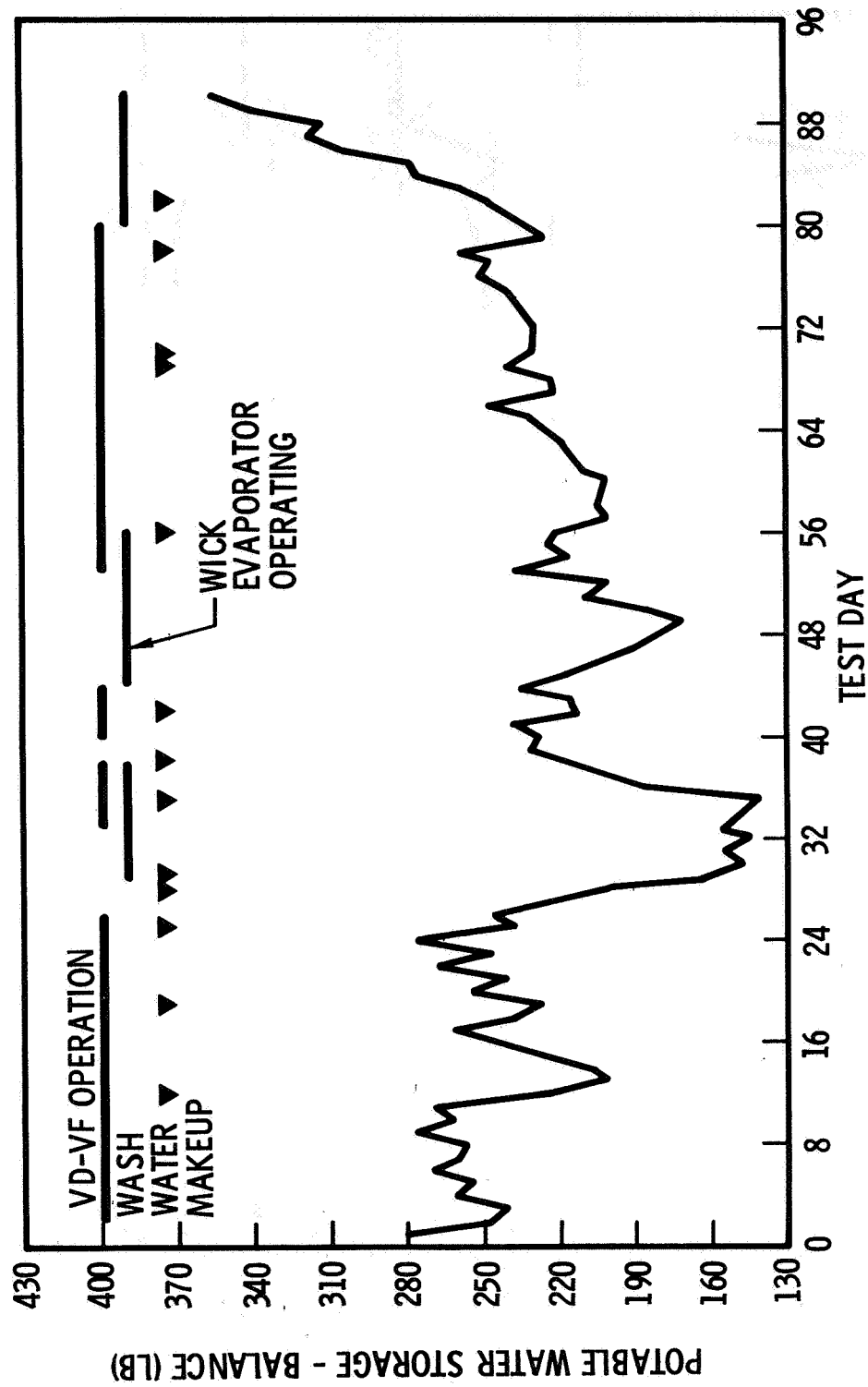


Figure 15.- Potable water daily inventory.

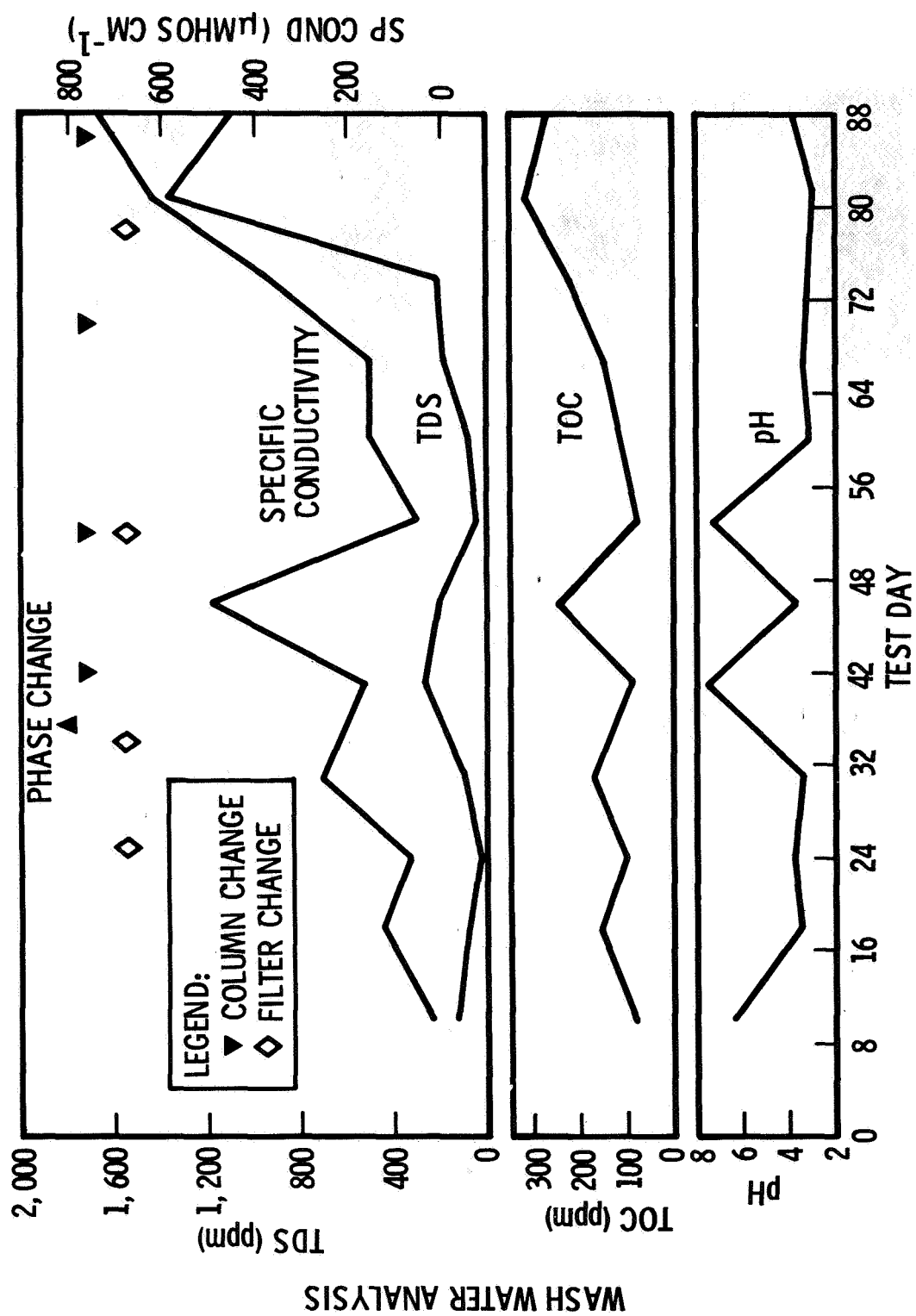


Figure 16.- Reclaimed wash water analysis.

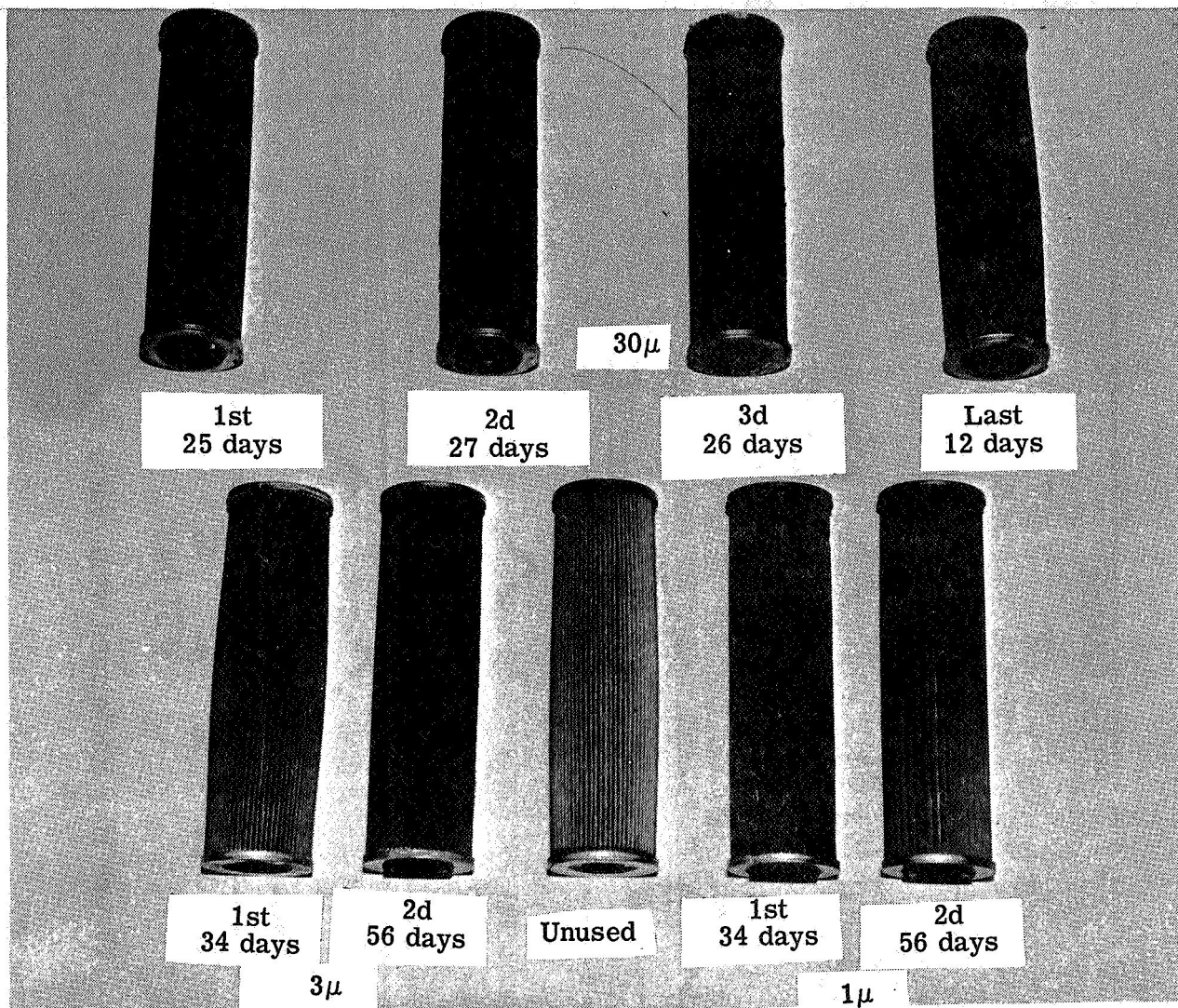


Figure 17.- Carbon column filters.

DESIGN AND DEVELOPMENT OF THE VACUUM-DISTILLATION,
VAPOR-FILTERED, ISOTOPIC-FUELED WATER RECOVERY
SYSTEM FOR THE 90-DAY MANNED SIMULATOR TEST

By Courtney A. Metzger
Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio

SUMMARY

The water recovery system for the 90-day manned-simulator test was furnished to the McDonnell Douglas Astronautics Company (MDAC) as an experimental system to recover potable water from pretreated urine and humidity condensate. This system, conceived and developed by the Aerospace Medical Research Laboratory (AMRL), uses radioisotopes for thermal energy and is based on vacuum distillation, vapor filtration, and catalytic oxidation of the contaminants in the vapor. This paper describes the design and development of the system, called VD-VF. This is the first operation of a water recovery system which uses isotopes in a manned chamber and is considered a significant technological breakthrough.

INTRODUCTION

Research conducted to obtain a process and a system design for the recovery of potable water from human waste during extensive space flights revealed that considerable thermal energy would be required for satisfactory operation. The large consumption of electrical energy prevents system acceptability when the energy drain is on the vehicle electrical supply system. The use of isotopes as a source of energy was investigated and found to be acceptable. The vacuum-distillation, vapor-filtration (VD-VF), catalytic-oxidation water recovery system designed by the U.S. Air Force to be used with electrical energy was redesigned to accept radioisotopes. Specific isotopes were designed for integration with the modified system. This report describes the design and development of the modified system. Results obtained by MDAC with the system during the 90-day test are given in paper no. 5 of this symposium.

SYSTEM DESCRIPTION

Development

The AMRL conducted an investigation (in 1967-68) of methods to remove organic contaminants from waste vapors. One of the methods evaluated was vacuum distillation followed by catalytic pyrolysis of the vapor. Tests showed

that contaminant removal could be accomplished by subjecting the catalyst to high temperature (1200° F). The AMRL during this period of time also designed and developed a vacuum-distillation, vapor-filtered water recovery system (VD-VF) described in references 1 to 3. While these developments were in progress, the Arde Company of Mahwah, New Jersey, developed a low-temperature cata-

lyst, designated Ardox[®], that showed promise. The VD-VF design permitted the incorporation of a unit containing the Ardox catalyst with a minimum modification of the system. To accomplish this modification, the charcoal bed and top membrane were removed and replaced by a catalytic oxidation unit charged with the Ardox catalyst. The system was subjected to several 30-day tests in which electric heaters were used as the source of thermal energy. These tests showed that the low-temperature catalytic-oxidation technique with vapor filtration showed good potential for use in recovering high-quality sterile water from human waste.

To qualify the VD-VF system further for space application, the AMRL initiated an in-house effort to design, develop, fabricate, test and evaluate a system with isotopes as the source of thermal energy, and the Atomic Energy Commission agreed to provide the required isotopes. The system was designed to operate continuously for a minimum of 90 days, reclaiming potable water from 24 pounds of human waste per day (9 pounds of urine and 15 pounds of atmospheric condensate). Figure 1 shows the general flow diagram for the system.

The initial design consideration was to develop a system requiring a minimum of moving parts and maintenance. The use of isotopes eliminated electric heaters, which had exhibited a high percentage of failure. The final design resulted in only two pumps and a metering device for transporting the waste product from the storage tank to the evaporator and to remove recovered water from the water storage tank. The use of space vacuum and the vehicle coolant system for the condenser completed the support required for operation. Approximately 4 pounds of the Ardox catalyst was used for each test.

The system was subjected to two separate continuous runs of 39 days and 36 days prior to the 90-day test. All urine processed was collected in a closed 6-liter container placed in a public rest room with no selection of the donors or control over their diet. Before the container was placed at the collection station, 15 ml of a 4:1:4 mixture of sulfuric acid, chromium trioxide, and distilled water was placed in the urine collector along with 2 to 3 drops of antifoaming compound per liter. This pretreatment was necessary to prevent the breakdown of urea to ammonia. When 6 liters was collected, the container was taken to the laboratory and the measured urine was mixed with an equal volume of distilled water to approximate a 50:50 mixture of urine and atmospheric condensate. This solution was then poured in the urine storage tank. A timer in the system allowed approximately 400 ml of the solution to be pumped from the storage tank into the evaporator every 20 minutes.

Evaporation occurs at temperatures between 100° to 120° F at pressures of 40 to 75 mm Hg. The vapor passes through a 0.4-micron Pall Ultipor[®] filter to remove microbial contaminants (a backup filter can be incorporated as shown in fig. 1) and then through the catalyst. The catalytic-oxidation unit is

maintained at 240° to 280° F. If any organisms pass through the filter, they are apparently removed by the catalyst. The vapor leaves the catalytic-oxidation unit through a tube which passes through the evaporator, where most of the heat is given up. The vapors are then passed through the condenser and the water is condensed and stored for future use. Once the waste solution enters the pump, and until the potable water is pumped off, the process is under vacuum. A flowmeter installed at the beginning of the process meters approximately 12 to 14 cm³ of room air per minute needed for the catalytic oxidation of the vapors.

The isotopes maintain the temperature in the evaporator at 100° to 120° F. The temperature in the evaporator is the key to satisfactory operation of the system. The volume of waste and the pressure in the evaporator control the temperature when the isotopes are used to supply the thermal energy. System failure can be caused by any one of the following subsystem malfunctions: failure of the sensing device which controls the liquid level in the evaporator (failure could allow the evaporator to go dry or to overfill); loss of vacuum; slowing or stopping of the urine pump; and rupture of the urine tube. Buildup of solids in the evaporator is another cause of failure. However, tests have shown that the system can process a 50:50 mixture of urine and atmospheric condensate at 24 pounds per day for up to 40 days with no problem of solid buildup. The system design includes two complete evaporators, and after 30 to 40 days of operation the second evaporator is fitted into the system and used for the next 30 to 40 days. The first evaporator is then stored, with the urine solids remaining in the used evaporator until the mission is completed. An evaporator change requires only the operation of four valves and the transfer of the five isotopes from the used system to the new one going into operation.

Radioisotope Capsule Design

Five heat sources were designed and fabricated by the Monsanto Research Corp., Miamisburg, Ohio, under the direction of the U.S. Atomic Energy Commission, Division of Isotopic Development. The AMRL requirements for the sources to be compatible with the VD-VF water recovery system are as follows:

	Evaporator unit	Catalytic-oxidation unit
Number of sources	4	1
Power (each capsule), watts	73.3 ± 1.5	48 ± 2.0
Operational temperature, °F	100 to 120	240 to 280
Outer dimensions:		
Outside diameter, in.	1.00	1.00
Length, in.	4.5	4.5

The capsules were designed and fabricated in accordance with Life Support II Heat Source Specification, Monsanto Research Corp. drawing No. 1-13297 (ref. 4). The capsule assembly (fig. 2) consists of two concentric cylinders (the clad tube and the liner tube) fabricated to fit at close tolerances at the interface to enhance the thermal conductivity. The capsules were designed for a 5-year life to meet long-duration testing and storage.

The liner tube was fabricated from a tantalum-10 percent tungsten material. The wall thickness of the liner is 0.030 inch with an outside diameter of 0.875 inch. The liner is 4.224 inches outside length with an internal length of 4.090 inches and is used to contain the fuel and to provide mechanical strength. (Plutonium-238, an alpha emitter, requires that a pressure vessel be used in this design to contain the resulting helium pressure buildup.) Caps were used to seal the liner.

The clad tube was fabricated from Hastelloy-C and designed to act as an interface between the highly reactive refractory metal liner and the chemically corrosive environment. The wall thickness is 0.050 inch with an outside diameter of 0.990 inch; the outside length is 4.438 inches. The capsule was sealed with caps.

Data derived from the stated dimensions and material (tantalum-10 percent tungsten) indicate 0.05 percent creep in 5 years at 1500° F since the stress builds linearly from 0 to 22,000 psi during the 5 years, and almost all the elongation occurs in the last year. Reference 5 indicated that for a 5-year lifetime, the $^{238}\text{PuO}_2$ microspheres are apparently compatible with the tantalum-10 percent tungsten material at temperatures up to 1500° F.

Refractory metals are incompatible with transition metals when in contact at elevated temperatures; however, the diffusion coefficient allows a depth of penetration of about 5 mils in 5 years, a rate which is slow enough for acceptability. Higher diffusion rates cannot be tolerated since the tantalum-10 percent tungsten liner will lose too much mechanical strength because of decreased wall thickness.

The 0.050-inch-thick wall of the clad tube appears sufficient for use at 1500° F if only air or inert gas environments are encountered. At 1500° F, Hastelloy-C exhibits good oxidation resistance. Air oxidation occurs to the extent of 2.3 mils in 1000 hours and 6.0 mils after 5000 hours at 1832° F (refs. 6 and 7). Environmental control must be maintained. Should corrosive atmospheres or surroundings be encountered, the heat source would have to be located in a shell compatible with both the heat source and the corrosive ambient.

REFERENCES

1. Metzger, Courtney A.; Hearld, Albert B.; Reynolds, Bobby J.; McMullen, Bobby G.; and Thomas, William H.: Low Temperature Catalytic Oxidation of Waste Water Vapors. AMRL-TR-68-48, U.S. Air Force, 1968.
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4. Davis, N. E.; and Johnson, E. W.: Life Support II Program - Final Report. MLM-1757, U.S. At. Energy Comm., Oct. 28, 1970.
5. Selle, J. E.; and Fitzharris, R. E.: The Compatibility of $^{238}\text{PuO}_2$ Microspheres With Refractory Metals and Alloys at 1000° C. MLM-1502, U.S. At. Energy Comm., May 1, 1968.
6. Anon.: Savannah River Laboratory Isotopic Power and Heat Sources - Quarterly Progress Report April-June 1967. Pt. I - Cobalt-60. DP-1120-I, U.S. At. Energy Comm., July 1967.
7. Hilborn, H. S., compiler: Savannah River Laboratory Isotopic Power and Heat Sources - Quarterly Progress Report January-March 1967. Pt. I - Cobalt-60. DP-1105-I, U.S. At. Energy Comm., May 1967.

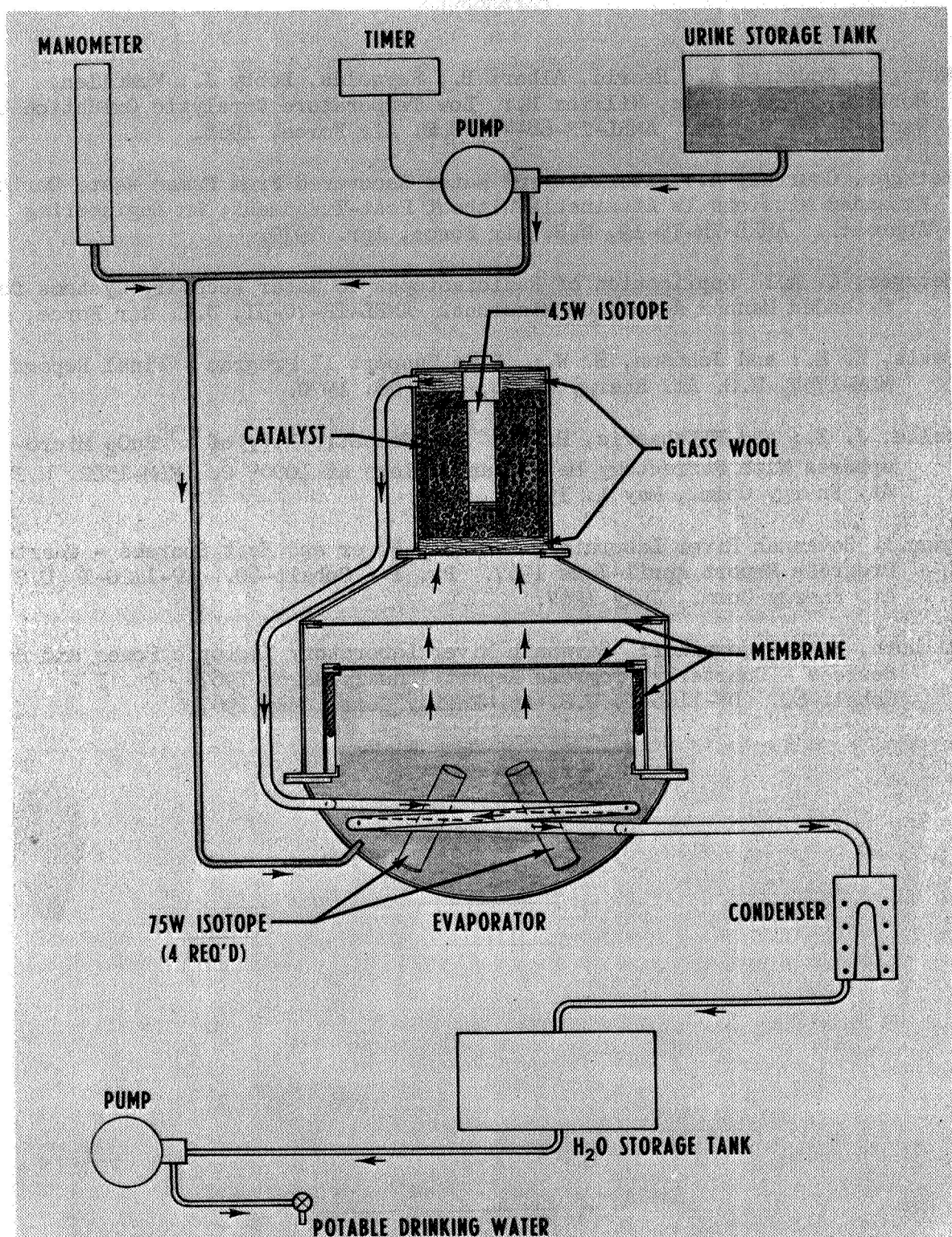


Figure 1.- VD-VF water recovery system with radioisotopes as energy source.

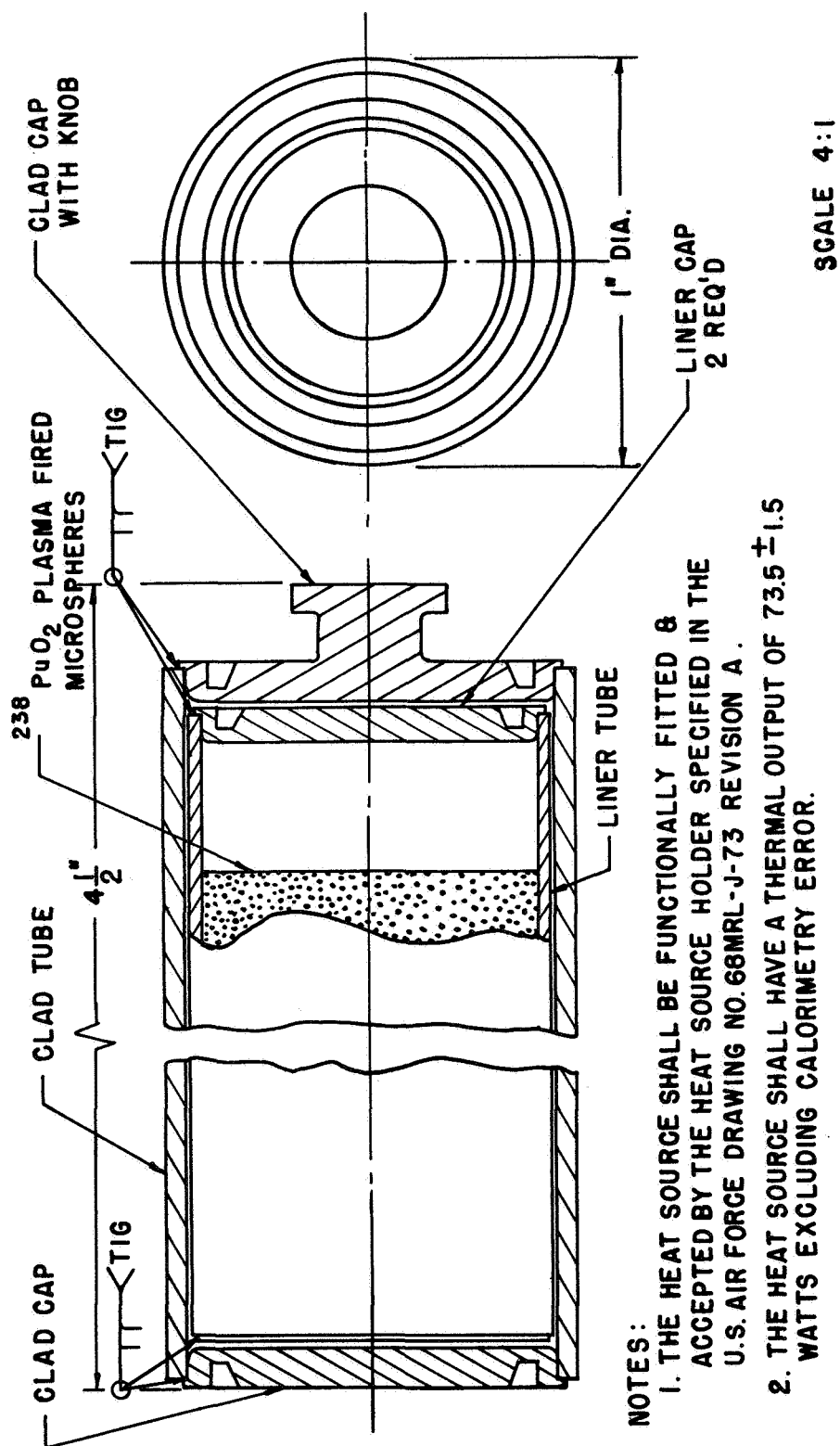


Figure 2.- Capsule assembly.

PERFORMANCE EVALUATION OF THE THERMAL CONDITIONING UNIT

By G. E. Allen

McDonnell Douglas Astronautics Company

SUMMARY

The configuration and performance of a thermal conditioning unit used during the 90-day manned test is presented. It includes an evaluation of its actual performance and comparison to the design performance. The analysis indicates that the unit's actual performance deviated from its design performance. However, comfortable temperatures were maintained in the living quarters throughout the test in spite of excessive thermal loads imposed by the solid amine unit which caused higher equipment room temperatures than desired during its operation. High reliability was realized throughout the 90 days and no failures required maintenance. Areas of improvement in the basic design concepts have been indicated, based on experience gained during the test, which would improve the operation and efficiency of the thermal conditioning unit. Recommendations are offered which will considerably lower the power required, the quantity of primary atmosphere circulated, and the associated noise level of the unit in addition to providing individual compartment temperature control.

INTRODUCTION

The prime function of the thermal conditioning unit is to maintain temperature levels suitable for human comfort by removing the sensible heat dissipated into the atmosphere. This heat dissipation into the SSS atmosphere was derived from occupants, high-temperature heat transfer fluid lines, electrical energy, and onboard isotope heaters. The rate of sensible heat dissipated from these sources varied as much as 40 percent and thus created a requirement for accurate and reliable modulating automatic controls.

In addition to accomplishing its prime function of sensible heat removal, the thermal conditioning unit was conceived around strict guidelines which limited designing for full optimum performance. These design guidelines included: (1) configuring to fit a predesignated minimum volume, (2) providing adequate performance over a wide range of cabin pressures, (3) fabricating from high-grade commercial or aircraft components, (4) limiting maintenance to filter changes, and (5) confining high temperatures resulting from excessive heat dissipation to the equipment area.

UNIT DESCRIPTION

The thermal conditioning unit configuration (fig. 1) utilized during the 90-day test consisted of two supply blowers in parallel which drew cabin atmosphere through aluminum mesh filters which had 4 ft² of surface area, an acoustical sound trap, and a flow tube for measuring flow rate. The

discharge from the two blowers passed through a noncondensing, extended-fin heat exchanger and an eliminator plate before entering the discharge acoustical sound trap. Conditioned atmosphere was furnished to the SSS living and bunk areas from a pressurized plenum with 19 low-induction-type perforated diffusers attached to its underside (ref. 1). Conditioned atmosphere was supplied to the equipment area by two rectangular diffusers mounted against the acoustical partition between the living and equipment areas. Return atmosphere from the living and bunk areas passed through either the acoustical trap mounted in the door or through the acoustical trap located in the partition.

Coolanol 35 was used in the liquid side of the heat exchanger as the coolant fluid. The SSS temperature was controlled by utilizing electronic sensors with a thermostat located in the living area approximately 5 ft from the deck. The electronic controls consisted of a modified Wheatstone bridge with a motor-balancing potentiometer, a low-limit heat exchanger fluid inlet controller, and an amplifier-discriminator circuit. The primary signal to balance or unbalance the bridge network was provided by the thermostat located in the living area.

A drain pan beneath the heat exchanger and an eliminator plate on the discharge side of the heat exchanger were provided to collect any condensate which might result from dew points higher than design levels.

UNIT PERFORMANCE

Performance of the thermal conditioning unit was monitored by thermocouples installed to measure temperatures within the three areas of the SSS, return atmosphere, heat exchanger discharge atmosphere, and inlet-outlet coolant fluid. In addition, atmospheric flow through the unit and coolant flow through the heat exchanger were measured. This was accomplished by using a calibrated flow tube with a differential pressure transducer for the atmosphere and a turbine flowmeter in the supply coolant to the heat exchanger. Signals from this instrumentation were fed into preselected channels of a low-speed digital system (LSDS) where values were recorded on a half-hour basis throughout the test. Magnetic tapes were removed periodically where they were processed and reduced into engineering units on an SDS 930 computer.

Results and Analysis

The results of the thermal conditioning unit performance were reflected in the SSS atmospheric temperature levels maintained during the 90-day test. Daily average temperatures for the bunk area, living area, and equipment area are shown on figure 2. Examination of these data indicates fluctuations of 3.5, 4, and 9.4 percent. Heat removal rate by the thermal conditioning unit heat exchanger varied between 14,272 and 19,980 Btu/hr. Total heat rejection rates for the SSS were between 22,800 and 29,500 Btu/hr during the test. The difference between the total rejection rate and the thermal

conditioning removal rate was picked up by cold plates or small extended surface compact heat exchangers, including those in the humidity control, solid amine unit, and other units. Peak thermal conditioning heat rates correspond well with high temperature periods. Causes for variations in heating rates and temperature fluctuations will be discussed later.

Actual Versus Design Performance

Design and actual performance parameters are tabulated in table 1 for comparison. Closer control of area temperatures was realized during the test than thought possible during the design formulation. However, the upper limit on equipment area temperature was exceeded during much of the test. This was due primarily to higher than expected (i. e., higher than allowed for during design) heat dissipation within the equipment area. Atmospheric diffusion rates in the equipment area were designed to remove 1.3 Btu/hr-ft³. Heat dissipation densities in this area exceeded 1.65 Btu/hr-ft³ during all but three periods during the 90-day test. These three periods occurred on test day 14 through 17, 20 through 24, and 81 through 90. Figure 2 shows the equipment area temperature dropping from the previous highs during these periods. All three periods occurred at a time when the advanced (solid amine) CO₂ removal unit was off line and the baseline (molecular sieve) CO₂ removal was on line. Examination of the sensible heat loss to the SSS atmosphere by each unit indicates the advanced CO₂ removal unit increased the thermal conditioning load by 6,482 Btu/hr.

Design heat rejection rate of the thermal conditioning unit never reached the design level even though heat dissipation densities for the equipment area were higher than expected. Reasons for this can be traced to the following factors: (1) method utilized to achieve comfort control and location of master controller and (2) low effectiveness realized from heat exchanger. Temperature control was achieved by allowing a master controller, located in the living area, to unbalance a bridge circuit. The unbalance caused a modulation in coolant fluid temperature supplied to the heat exchanger. Temperature modulation of coolant fluid was accomplished by mixing return coolant with cold supply coolant in proper quantities. A submaster sensor in the circuit acted as a low-limit controller and prevented achievement of fluid temperatures which would cause condensation within the heat exchanger. This control concept, designed to satisfy comfort conditions only in the living and sleeping areas, allowed a single discharge temperature from the heat exchanger. Therefore, high heat dissipation in the equipment area had only an indirect influence on the control system. Had the master sensor been located in the equipment area, control signals would have been generated resulting in overcooling the living and sleeping areas.

The heat exchanger effectiveness achieved during the test was considerably below that indicated by the manufacturer for this service. Calculations show the realized effectiveness to be approximately 0.2 (i. e., $\epsilon_T = 0.2$) rather than 0.5 as indicated by the supplier. Based on this effectiveness, the design heat rejection rate would not have been met at the inlet and outlet temperatures specified. It should be noted that standard heat exchangers of

this type are commonly designed and rated for use with water as the coolant. Improper techniques were apparently employed in rating the standard unit for Coolanol 35 use. [Note: Heat transfer coefficient (h_c) for Coolanol 35 is 1/10 of that for water (flow and inlet temperature being equal).]

Some humidity condensation resulted in the heat exchanger, particularly during periods of high atmospheric dew point. The condensation occurred on the end of the heat exchanger due to an atmospheric leak between the end plate and the cold tube return bends. A drain pan was installed to catch the water as the leak was discovered after the heat exchanger was installed. Condensation from this source averaged 1.2 lb/day. During the test the crew installed a line from the pan drain over to the overflow sump beneath the wick evaporator condenser separator.

The atmospheric filters installed in the return duct to the thermal control did not require changing during the test. Spares were carried onboard in event clogging occurred.

CONCLUSIONS AND RECOMMENDATIONS

The performance of the thermal conditioning unit adequately met the mission objectives even though several of the design parameters were exceeded. Satisfaction was expressed by the crew with the temperatures maintained and noise levels achieved throughout the test. Recommendations for an improved thermal conditioning unit would include elimination of deficiencies experienced plus a general upgrading of the complete concept of temperature control within a confined area. Primary recommendations for analysis and testing are outlined as follows:

- A. Achieve at least 70 percent of the sensible heat removal from the SSS by use of cold plates located at the source of the dissipation. A large power penalty must be paid when removing this heat by circulation of a temperature-controlled atmosphere versus a temperature-controlled fluid.
- B. Design the thermal conditioning unit to provide individual area temperature control. This can be accomplished without individual area heat exchangers if a bypass section with bypass dampers is installed with a main heat exchanger equipped with face dampers.
- C. Minimize the quantity of primary atmosphere circulated by use of high-induction diffusers. Sound generation in a thermal conditioning unit is a strong function of the atmospheric flow rate and system pressure. If the atmospheric flow rate can be significantly reduced by only slightly increasing the pressure, the sound generation will be lower.

REFERENCES

1. Allen, G. E., Bonura, M. S., Thomas, E. C., and Putnam, D. F.:
Integrated Temperature Control, Humidity Control, and Water
Recovery Subsystems for a 90-Day Space Station Simulator Test.
McDonnell Douglas Paper No. MDAC-WD 1241, June 1970.

TABLE 1.- PERFORMANCE OF THERMAL CONDITIONING UNIT

	Design performance	Actual test performance
Temperatures		
Living area	70 ± 5	74 ± 1.5 (avg 74.1)
Bunk area	70 ± 5	73 ± 1.3 (avg 72.8)
Equipment area	70 ± 5	77 ± 3.6 (avg 77.9)
Inlet heat exchange fluid	48 ± 4	38 ± 4
Flows		
Atmospheric	2000 CFM (actual)	2130 CFM (actual)
Heat exchanger (coolant 35)	16 CFM	Approx 19 CFM
Normal maintenance		
During test	None	None
Filter changes	One	None
Sound level		
Equipment area	NCA 60	
Crew quarters	NCA 60	
Bunk area	NCA 50	
Total heat rejection	24 000	19 980

THERMAL CONTROL SYSTEM SCHEMATIC

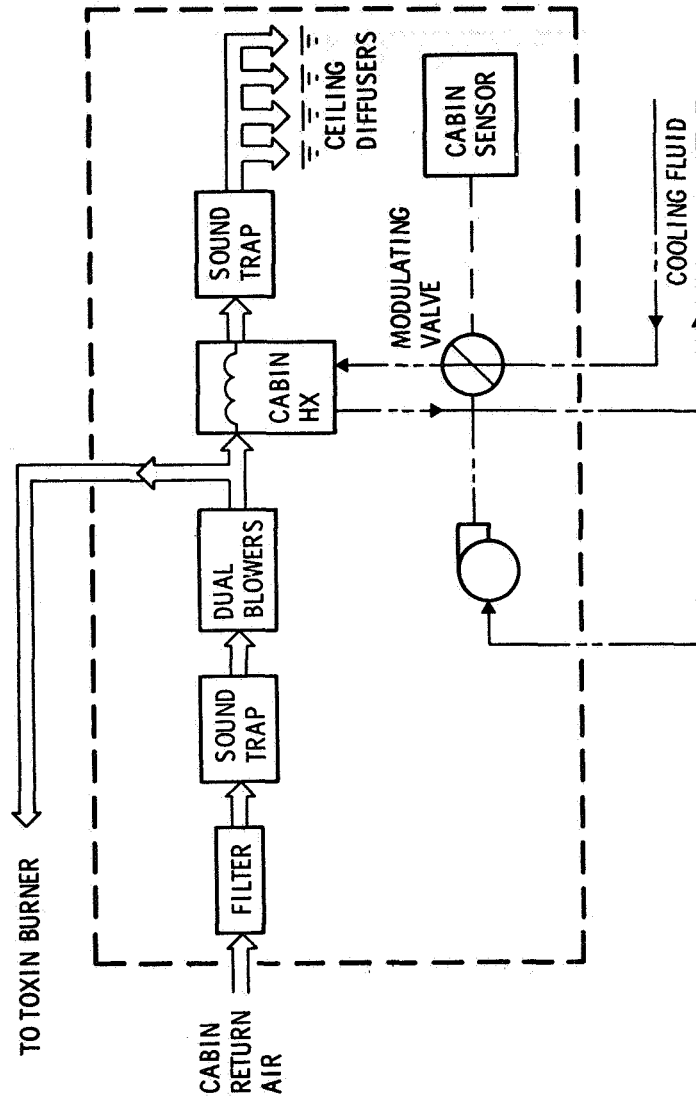


Figure 1

SIMULATOR TEMPERATURE

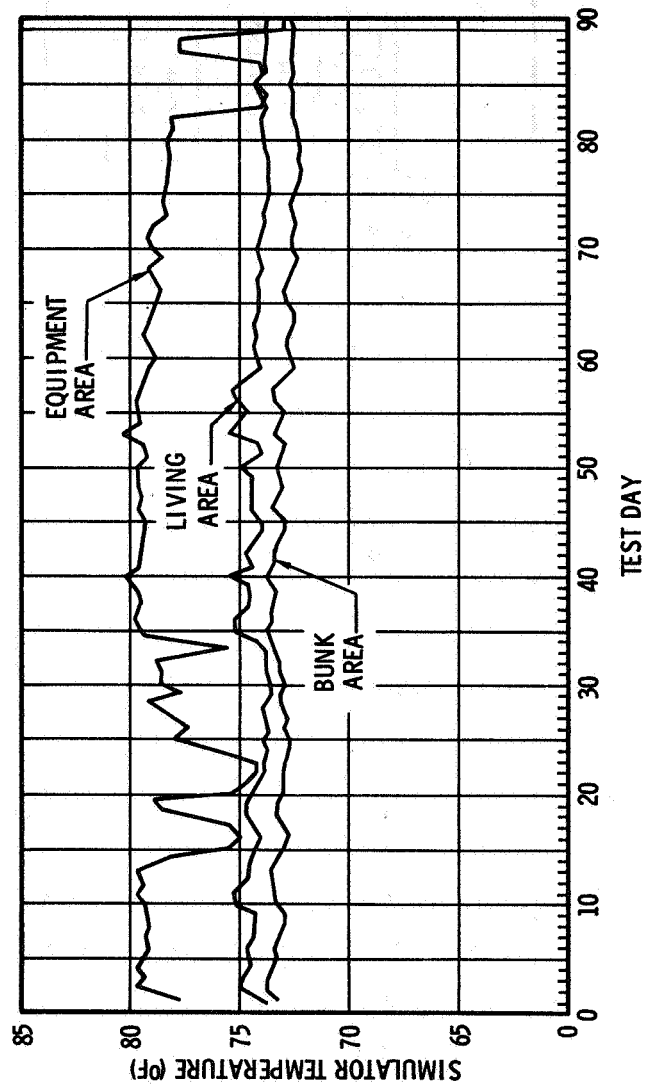


Figure 2

PERFORMANCE OF THE CO₂ CONCENTRATORS

By E. S. Mills and T. J. Linzey

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SUMMARY

The performance of the CO₂ concentrator system consisting of the advanced baseline solid amine system, the backup molecular sieve system, and the emergency lithium hydroxide-Gemini CO₂ removal unit was satisfactory. The average CO₂ concentration in the cabin over the 90-day test time averaged approximately 5 mm Hg rather than the intended 4 mm Hg, primarily because of the problems with adjusting the solid amine concentrator. The solid amine unit was used for CO₂ control during the majority of the first 81 days of the test. The solid amine required a significant amount of maintenance; although this was not unexpected, considering the state of development. The backup molecular sieve CO₂ concentrator unit was used for CO₂ concentration when the solid amine was inoperative. The molecular sieve was operated during test days 14 through 25, 33, 34, and 81 through 90. The solid amine unit was operated part of test days 18 and 19 to check repairs being made. The major problems with the solid amine were maintaining the correct percentage of water in the beds during absorb and desorb cycles and keeping the inlet air at the correct temperature for the bed conditions. The major mechanical problems were a sticking valve that required manual cycling, a solenoid valve sticking open, and the clogging of the condensed water drain in the exhaust condenser. When adjusted correctly, with the proper water balance in the beds, the unit maintained the CO₂ cabin concentration at the specified level.

The performance of the molecular sieve CO₂ concentrator was satisfactory, serving the role of backup when needed. Only minor problems were encountered, a leaking valve, short bakeouts required after starting up from standby conditions, and a nonfunctioning zero-g separator. The negative pressure device used with the LEM elbow zero-g water separator did not function properly. Before the start of the test, this was replaced by a collection tank installed downstream of the separator to collect the condensed water.

Operation of the LiOH unit was not required during the test.

INTRODUCTION

The function of the CO₂ concentrator is to maintain the partial pressure of CO₂ at approximately 4 mm Hg and to provide pure CO₂ for processing in the Sabatier reactor for atmosphere recovery. This function is provided by an advanced solid amine system with a molecular sieve unit as backup and a LiOH CO₂ removal unit for emergencies.

The solid amine concentrator is an experimental unit built specifically for the 90-day test from off-the-shelf hardware. It utilizes a weak base amine ion exchange resin, IR-45, for CO₂ absorption. It was built by Hamilton Standard under contract to NASA-LRC.

The molecular sieve CO₂ concentrator was used for CO₂ concentration during the 1968 60-day NASA/MDAC chamber test, rebuilt, and updated. The major changes to the unit are

- A. Replacement of the two four-way electric air diverter valves isolating the silica gel beds with four three-way pneumatic valves.
- B. Addition of an Apollo suit compressor for circulation of cabin air through the unit.
- C. Replacement of the cycle timer with a more positive snap action switch, cam timer.
- D. Addition of a filter upstream of the CO₂ compressors to remove any dust coming from the beds.
- E. Complete rearrangement of component locations to obtain access for maintenance and part replacement and to meet installation space limitations.

DESCRIPTION OF OPERATION

Solid Amine

The basic components of the solid amine CO₂ concentrator units are three separate beds packed with solid amine ion exchange resin particles, two circulation fans (one redundant), two condensing heat exchangers, two compressors to pump CO₂ to the accumulator (one redundant), a boiler and superheater, two water pumps (one redundant), timer and cycle control unit, manifolds, and sequence control valves. A schematic of the unit is shown in figure 1.

Dehumidified cabin air from the humidity control outlet is drawn into the unit by the circulation fan. The air then passes through a filter and a condenser/heat exchanger to condition it to the desired temperature and relative humidity. The air then enters the absorbing amine canister(s) where the CO₂ contained in the air stream is removed. The purified air is then returned to the cabin through the second condenser/heat exchanger. This heat exchanger cools the air and condenses the water removed from the absorbing bed during the absorption reaction. This water is passed to the water storage accumulator. The desorption of the amine beds is accomplished with superheated steam. Water is pumped from the storage accumulator to a two-stage water boiler. Heat is supplied from the Coolanol 35 heating fluid circuit. The steam generated in the boiler/superheater at

210±3 °F is passed through the amine bed where it condenses on the amine resin. The resultant heat and water release the CO₂ from the amine particles. The CO₂ is then reabsorbed downstream in the bed. After sufficient steam is condensed in the bed and the bed temperature is elevated, the CO₂ is eluted from the canister. The CO₂ is then pumped to the CO₂ storage accumulator. The temperature sensor in the bed discharge line senses when the steam breaks through, indicating the end of CO₂ desorption. A diverter valve then diverts the bed effluent (steam and water) to the cabin through the second condenser/heat exchanger. Either two- or three-bed operation is possible. In the three-bed mode, two beds are absorbing with the third on desorb.

Molecular Sieve

The basic components of the molecular sieve unit are two silica gel beds in parallel, a heat exchanger, a circulation blower (Apollo suit compressor), a heat exchanger, two molecular sieve beds in parallel, a sequence timer, manifolds, and sequence control valves. A condenser and zero-g water separator are provided to remove water vapor from the silica gel beds desorption air stream. A schematic of the unit is shown in figure 2.

Function of the unit is as follows: cabin air is drawn through the adsorbing silica gel bed where the moisture in the air is removed to a dew point of -50 to -70 °F. The flow then enters the circulation blower and passes through the heat exchanger cooling it to 40 to 50 °F. The cool, dry air then passes through the adsorbing molecular sieve bed where the CO₂ is removed. Approximately 80 percent of the dry, CO₂-free gas is discharged into the cabin. The remaining gas is passed to the desorbing silica gel canister which has been heated to approximately 300 °F with hot Coolanol. This dry gas flow picks up the water being driven off the beds by the heat and carries it to the condenser and separator where it is collected and passed to storage. The desorbing molecular sieve bed is being regenerated, heating to 300 °F with the hot Coolanol and evacuating with a vacuum pump (or external vacuum system if not necessary to collect the CO₂). The vacuum pump pumps the desorbed CO₂ to an accumulator for storage. To remove the cabin gas from the canister voids at the start of the desorb cycle, the gas is pumped back to the cabin through the adsorbing molecular sieve bed for a few minutes. This insures pure CO₂ when flow is switched to the accumulator. After 30 minutes of desorption, cold Coolanol is pumped to the desorbing beds to cool them before cycling to the adsorption cycle. After 45 minutes, the timer sequences the valves to divert the cabin flow through the regenerated beds and place the beds now requiring regeneration on desorption cycle. Hot Coolanol will then flow through the desorbing beds and the cycle is repeated. The time for a complete adsorption, desorption, and cooling cycle is 90 minutes.

Lithium Hydroxide

For emergency use, in the event both the primary and backup CO₂ concentrator units were inoperative and repairs could not be completed before

the CO₂ concentration reached excessive levels, a lithium hydroxide removal unit was installed. It had the capacity of 28 man-days CO₂ removal.

PERFORMANCE DURING THE 90-DAY TEST

The cabin atmosphere CO₂ concentration during the 90-day run is shown in figure 3. The abnormal operation peaks are numbered for reference. The significant events are as follows:

Test Day

- | | |
|-----|--|
| 3 | Main valve on bed 1 did not automatically cycle. Crew had to rotate valve manually. This occurred approximately 200 times until day 14. |
| 13 | Peak (1). CO ₂ removal efficiency reduced. It appears bed 2 was excessively wet, due to delays in performing the above noted manual valve sequencing. Attempts to dry bed 2 failed. |
| 14 | Unit shut down. Molecular sieve started up. Drying of solid amine beds accomplished. |
| 18 | Bed 1 isolated because of valve problem. It was suspected that valve sticking caused bed 2 to overwet. Operation on beds 2 and 3 initiated; molecular sieve shut down. |
| 19 | Peak (2). Solid amine could not maintain the cabin CO ₂ concentration within acceptable limits. Molecular sieve placed in operation. |
| 25 | Problem in solid amine traced to shifting of inlet air thermocouple reference junction by +15°F. Instrumentation recalibrated. Molecular sieve shut down. Solid amine restarted, operation satisfactory. |
| 26 | Peak (3). Solid amine not maintaining CO ₂ level. Evaluation |
| 28 | to showed steam generation rate too low. Water filter element changed, rate increased. Operation satisfactory. |
| 33 | Peak (4). Pneumatic compressor on solid amine valve actuation system failed. Solid amine shut down. Molecular sieve started up. |
| 34 | Molecular sieve performance marginal. Bakeout performed. Unit performance satisfactory after bakeout. Restarted solid amine unit, with gaseous nitrogen supplied to unit, replacing air compressor function. |
| 45 | Peak (5). Solid amine could not maintain the required CO ₂ levels. |
| and | It was suspected bed 2 was excessively wet. Bed 2 dried by "dry" |
| 46 | desorb technique. Operation improved. |

- 48 Condensate was observed to be flowing from the condenser outlet. Investigation revealed the condenser was full of water. The drain line was plugged. This caused excessive wetting of bed 2. The physical layout of the system allowed water trapped in the heat exchanger to drain back from the heat exchanger inlet to the discharge line from bed 2, and into bed 2. Therefore bed 2 received excessive water. The water line was disconnected and backflushed through the heat exchanger.
- 58 Peak (6). High cabin CO₂ level. The heat exchanger again was plugged, causing excessive wetting of the beds. The heat exchanger was blown out again, beds "dry" desorbed. Performance improved. (This occurred approximately every 2 to 3 days until end of operation.)
- 65 Peak (7). Water filter changed allowing greater steam generation rate. Improved performance.
- 74 Plug fell out of amine bed 3 canister allowing several pounds of amine resin to leak out of the canister. Hole plugged. Performance marginal.
- 76 Peak (8). Solid amine could not maintain required CO₂ level. Cycle time shortened from 13 to 12 minutes.
- 80 Cycle time reduced to 11 minutes in attempt to improve performance.
- 81 Peak (9). Bed 3 performance negligible. Bed 3 shut down, bed 1 activated. Cycle time increased from 11 to 12 minutes. No effect. Cycle time increased to 13 minutes; bed 1 was very difficult to cycle manually. Unable to obtain required performance in bed 1.
- 81 Unit shut down at 1,533 hours.
- 81 Molecular sieve started.
- 90 Test terminated.

One significant factor is the thermal balance of each unit. The requirement for heat supply and cooling can constrain vehicle design. The typical thermal balance of the molecular sieve and solid amine units is shown in figures 4 and 5, respectively.

CONCLUSIONS AND RECOMMENDATIONS

The solid amine unit demonstrated its effectiveness for maintaining cabin CO₂ concentration. The problems encountered can be easily solved by design improvements. The water balance problem can be overcome by

placing humidity level detectors in the beds and automatically or manually controlling the steam generation rate to each bed. The problem of flooding can be eliminated by redesign of the condenser to allow filter changing. The solid amine contributes a greater latent and sensible thermal load to the atmosphere than desired. Optimization of operation and hardware will undoubtedly improve this penalty. The 90-day test was the first time that a solid amine CO₂ concentrator unit operated in a manned test.

The performance of the molecular sieve during the test was satisfactory. For future operation, a more efficient water separator may be used as well as more efficient molecular sieve material.

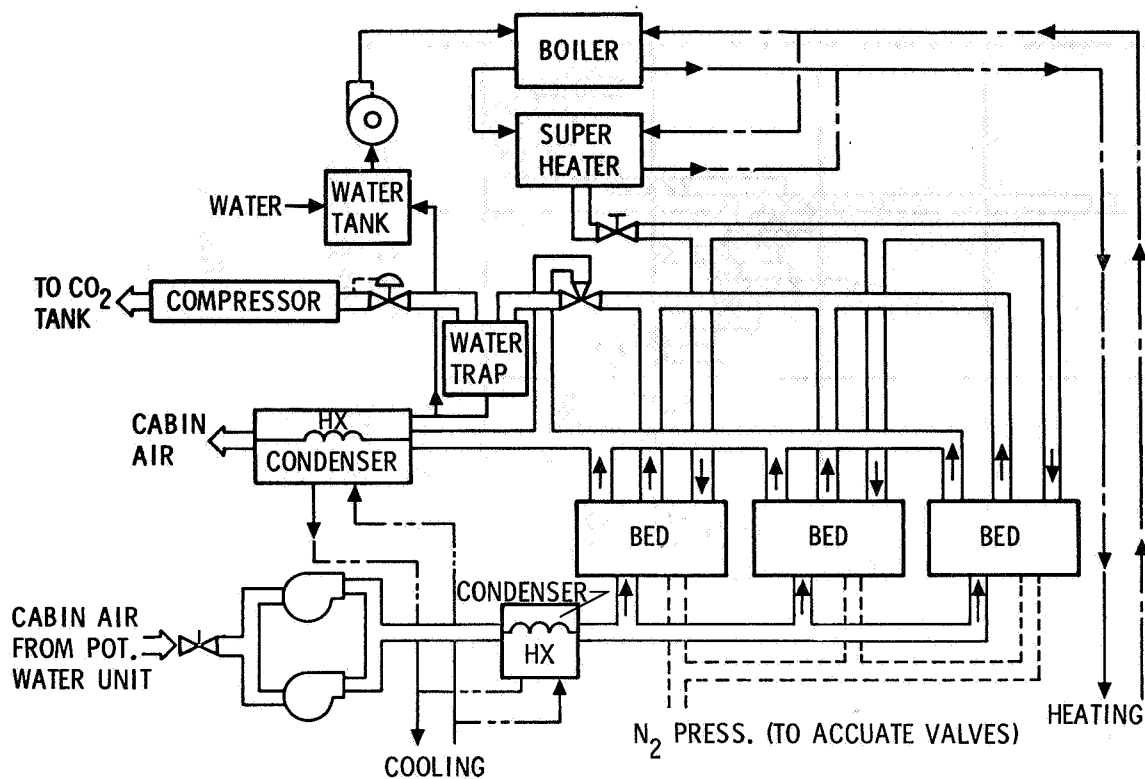


Figure 1.- CO₂ concentrator - solid amine unit.

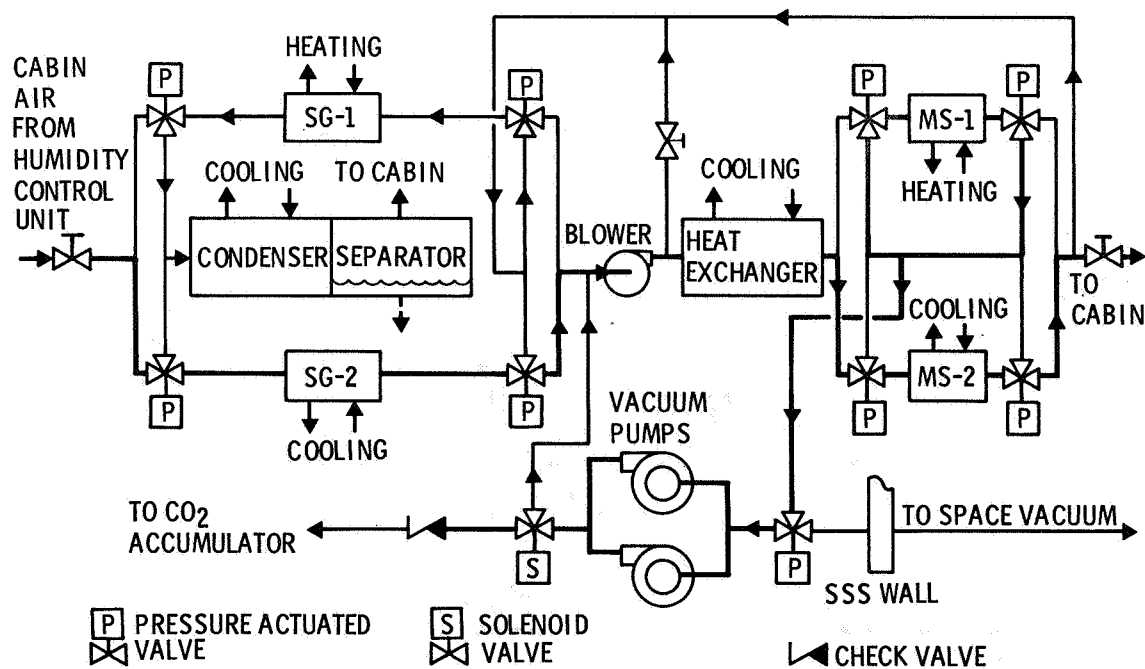


Figure 2.- CO₂ concentrator - molecular sieve unit.

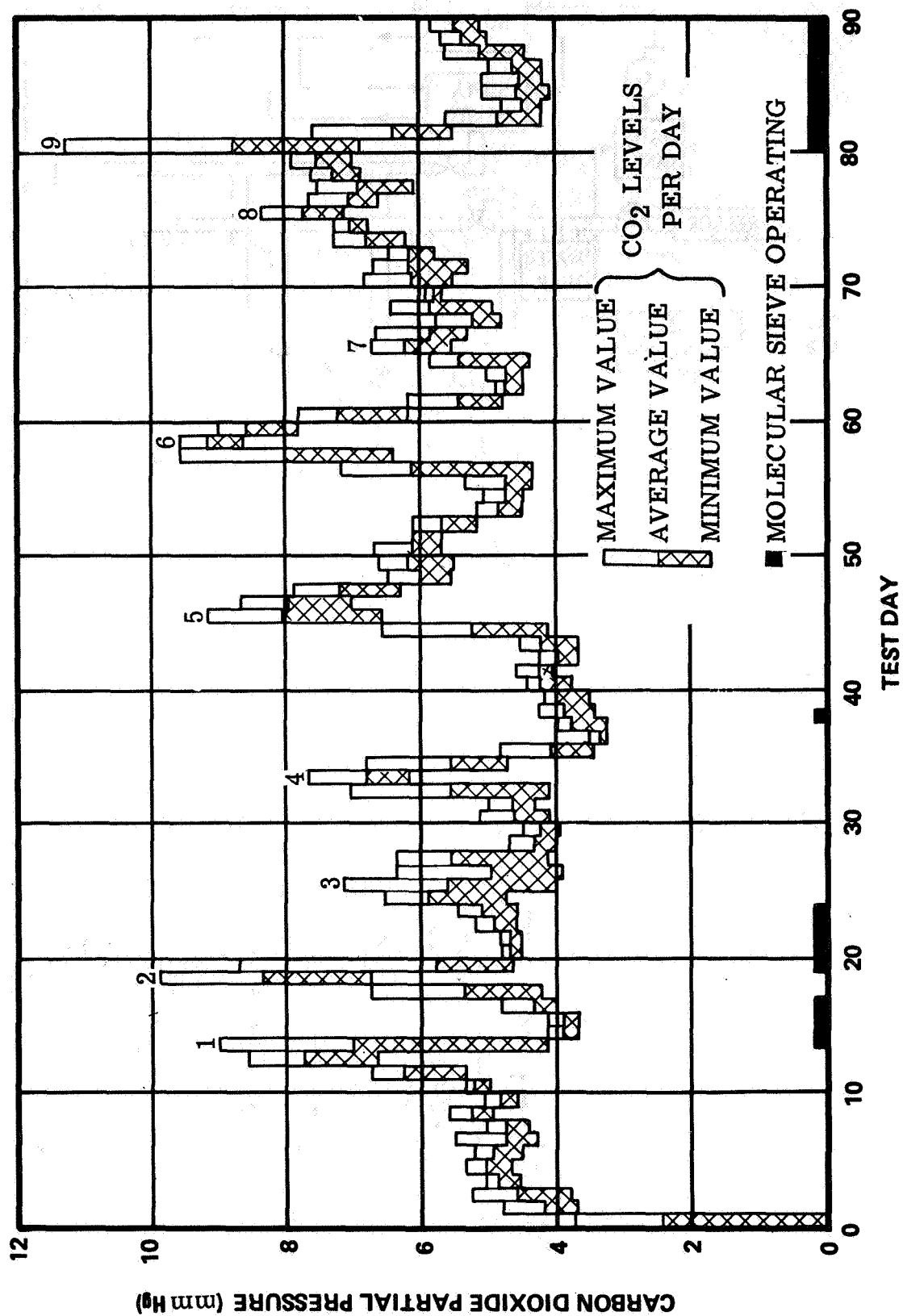


Figure 3.- Carbon dioxide partial pressure.

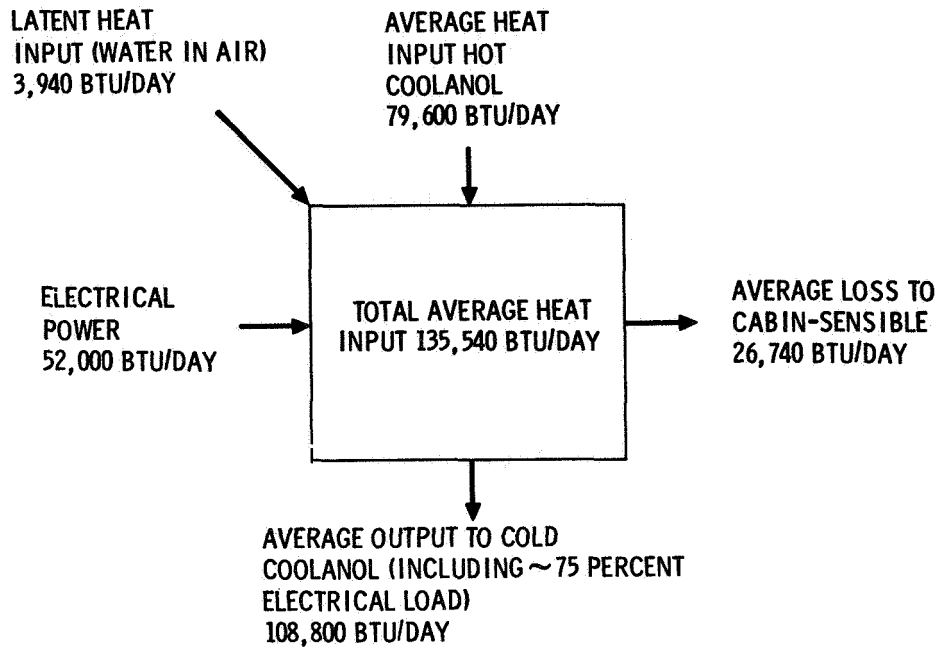


Figure 4.- Thermal balance of molecular sieve unit.

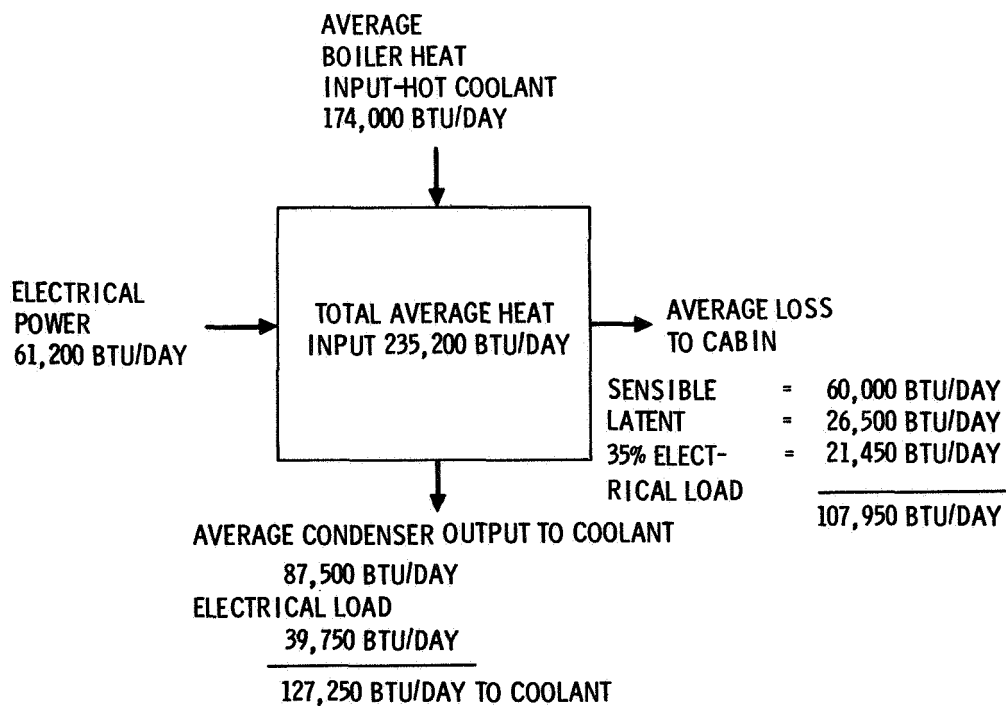


Figure 5.- Thermal balance of solid amine unit.

OPERATIONAL CHARACTERISTICS OF THE INTEGRATED SABATIER/TOXIN BURNER UNIT

By J. F. Harkee

McDonnell Douglas Astronautics Company

SUMMARY

Operation of the Sabatier reactor during the initial 30 days of the 90-day manned test was somewhat complicated by catalyst poisoning caused by trace quantities of Freon-113 (TF) appearing in the carbon dioxide. Operation returned to normal after replacing the catalyst and adding a charcoal trap to remove the contaminant from the carbon dioxide. The Sabatier unit produced about 350 lb of water during the test. The average water production rate for the last 60 days was 4.38 lb/day. The reactor converted over 95 percent of the hydrogen processed to water. The toxin burner operated normally throughout the test.

INTRODUCTION

The Sabatier functions to recover oxygen from the carbon dioxide exhaled by the crew. The carbon dioxide is reacted with hydrogen from the electrolysis unit at a temperature of about 700°F in the presence of a catalyst to produce water for the electrolysis unit, methane (exhausted), and heat.

The toxin burner oxidizes hydrocarbons, methane, and carbon monoxide to carbon dioxide and water vapor. This reaction also occurs at a temperature of 600° to 700°F in the presence of a catalyst. Because of the low concentration of oxidizable material, heat must be added to maintain reaction conditions.

The integration advantage is to utilize the heat produced by the Sabatier to support the toxin burner operation thereby reducing spacecraft power requirements.

DESCRIPTION OF UNITS

The primary components of the Sabatier unit are the CO₂ pressure regulator, H₂ and CO₂ mixture control valves, Sabatier reactor, reactor pressure control valve, and a zero-g condenser/water separator.

The toxin burner unit consists of a regenerative heat exchanger, an electric heating element, a temperature controller, and a catalytic (Hopcalite) reactor. A schematic of the units is presented in figure 1.

The Sabatier obtains CO_2 at accumulator pressure. The CO_2 flows through the pressure regulator, which obtains a pressure reference from the H_2 supply. The regulated CO_2 then flows through a control valve under critical flow conditions. The H_2 flows directly to a separate critical flow-control valve. The two gas streams mix downstream of the control valves and then flow into the reactor. The reactor is a jacketed cylinder; the inner cavity contains the nickel-on-kieselguhr catalyst. Air from the toxin burner regenerative heat exchanger flows through the jacket to remove reactor heat. The catalyst bed is normally operated at a pressure of from 460 to 505 mm Hg and a temperature of 500° to 750°F . The CO_2/H_2 mixture reacts to form methane (CH_4) and steam.

The product gases containing some excess CO_2 and a small amount of unreacted H_2 leave the reactor and flow through the zero-g condenser/separator and then a conventional backup condenser where the steam is condensed and separated as water. The CH_4 and unreacted gases then flow through the critical-flow reactor pressure-control valve to the Space Station Simulator (SSS) vacuum subsystem. The zero-g condenser/separator is approximately 8 in. long by 4 in. wide by 1-1/2 in. high and is divided into two compartments by a partition of porous metal. Chilled water wets one surface of the porous plate. The reaction gases flowing along the opposite surface are cooled and the steam condenses and wets the porous surface. The condensed water will then transfer through the porous plate into the cooling water by capillary action and a controlled pressure difference. Product water flowing through the plate increases the displacement of a negative-pressure device, triggering the magnetic latching of a reed switch which activates the proper valving to allow compressed CO_2 to displace the water into the electrolysis water storage tank. The backup condenser collects any water it recovers in a small accumulator. A float switch in the accumulator activates a positive displacement pump which also discharges the condensate into the water storage tank.

The toxin burner obtains SSS air from the discharge side of the thermal control unit blowers at a rate of about $90 \text{ ft}^3/\text{hr}$. The air is forced through the regenerative heat exchanger, where it is preheated by the exit gas stream. The gas then flows through the cooling jacket of the Sabatier reactor where it absorbs a portion of the reaction heat (and likewise cools the reactor). The gas then passes through the electric heater, where the gas temperature is increased to the proper oxidation temperature (predetermined by the temperature controller). The gas then traverses the catalytic reactor bed to the hot side of the regenerative heat exchanger and then exits to the cabin.

OPERATION OF SABATIER REACTOR

During the initial part of the test, many valve adjustments and stabilization of reactor temperature with the starter heater were required. The maintenance activity during the test is summarized on table 1. The unexpected attention requirements were partially caused by the frequent changes in hydrogen sources and pressures affecting H_2/CO_2 mixture ratios. At the middle of the third week, it became apparent that the reactor was not operating in a normal manner. The temperature profile in the reactor shifted toward the aft end of

the reactor, and a tendency for the reaction to be blown out the end of the reactor was experienced. Poisoning of the catalyst was suspected. Since electrolysis produces almost pure hydrogen, it seemed likely that the poison was entering with the carbon dioxide. On the 16th day, the reactor was switched to commercial grade bottled CO₂ to observe if the catalyst would "clean up" and, if not, to ascertain the degree of catalyst deterioration. Samples of CO₂ from the onboard accumulator were analyzed to determine what trace contaminants might be present. Contaminants found, in addition to the expected O₂ and N₂, were ethanol, acetone, and Freon-113 (TF). A brief review of the literature indicated (ref. 1) that nickel-hydrogenation catalyst could be poisoned by compounds containing sulfur or halogen groups by a mechanism of tying up the "active" sites of the catalyst. Freon-113 contains both chlorine and fluorine atoms of the halogen group. The next step was to determine if significant amounts of the Freon-113 would be thermally decomposed under reactor conditions. Mr. David Grana of NASA LRC arranged to operate its Sabatier reactor with similar Freon concentrations and conditions. LRC quickly reported that Freon decomposition was found to be in excess of 80 percent, with no halogens being found in the exhaust gas stream, but with significant concentrations of halogens being present in the product water.

The source of the Freon-113 is attributed to the cleanup following a failure of a Coolanol line during the unmanned SSS baseline test. Freon was used as a final wash to remove all traces of the Coolanol. Though the SSS was ventilated for several days before the repeat of the unmanned baseline test, it is believed that trace quantities remained absorbed on surfaces within the simulator. The trace quantities that desorbed during the test were removed by the CO₂ concentrator units.

Reactor operation on bottled CO₂ did not significantly improve. Reaction during this period remained in the aft end of the bed with occasional "flame-outs". The reactor operated to the 22nd day on bottled CO₂, when a charcoal trap was placed in the cabin CO₂ delivery line. Gas samples taken downstream of the charcoal trap indicated that the charcoal was effectively removing all organic trace contaminants. Operation continued without improvement utilizing CO₂ from the molecular sieve until the 28th day when it was decided to replace the catalyst. It is interesting to note here the past history of the catalyst. This catalyst was used for 15 days before the 60-day manned test, 52 days during the 60-day manned test, about 25 days in bench testing prior to the 90-day manned test, 8 days during the preliminary unmanned and manned tests, and 28 days during the 90-day manned test, giving a total operational history of about 128 days. No sign of deterioration was observed prior to the unmanned baseline test. The reactor was down the 28th and part of the 29th day while the crew replaced the catalyst and leak tested the reactor and subsystem. The used catalyst was placed in a No. 2 tin can and sealed while awaiting the next scheduled pass-out. The new catalyst (Ni-0104T-1/8", Harshaw Chemical Company) was placed in an open aluminum pan until the exothermal reaction with the oxygen-rich atmosphere was complete to avoid any crew handling accidents while loading the reactor. After completion of loading and sealing the reactor, it was leak checked by pressurizing it to 30 psia with nitrogen and immersing in water. After assembly into the subsystem, the unit was evacuated to 5 psia and preheated to 300° F to demonstrate gas-tight integrity at elevated temperatures.

The reactor was then heated to 350° F and slowly purged with hydrogen to activate and reduce the catalyst. The unit was then started using routine procedures.

Operation with the new catalyst was smooth and required little attention by the crew. Water production increased from an average of 2.7 lb/day for the initial 30 days to 4.38 lb/day for the remaining 60 days. These values as well as the daily water production quantities are shown in figure 2. This figure also includes the 25.2 lb of water lost through the exhaust. Hydrogen utilization is shown on figure 3 and carbon dioxide utilization is shown on figure 4.

Some crew attention was used to remove the reactor insulation during the period when the toxin burner unit was intentionally turned off (to compensate for the decrease in reactor cooling capacity).

The reactor was shut down for partial periods of four of the last 60 days of the test because of interruption of supply gases. The charcoal trap had a capacity of about 120 in³ of charcoal and a useful life of about 11 days. Biweekly testing of the CO₂ both upstream and downstream of the charcoal traps was accomplished. However, the shifting aft of the reaction within the Sabatier turned out to be the most sensitive method of determining when the charcoal needed replacing. During the short period of time (approximately 20 minutes) required to change the charcoal, CO₂ bypassed the trap to maintain reaction. For a period of 6 to 24 hours after changing the trap, the reaction remained stable in the aft end of the reactor before returning to the normal position.

On test day 87, methane concentration in the SSS increased significantly. The Sabatier, a producer of methane, was then reduced in operating pressure from about 530 torr to 480 torr, well below cabin pressure. The SSS methane concentration then leveled off and began to decrease. However, the reactor pressure control valve was in the fully open position to maintain the pressure at a lower than cabin level. On the 88th day, the Sabatier was shut down and leak tested. A gross stress corrosion failure along the minimum stress axis of a 90-degree bend in the exhaust line between the reactor and the condenser was found. The corrosion was attributed to hydrogen chloride and hydrogen fluoride in the exhaust. The line was replaced by the crew, and the reactor operated normally for the remainder of the test.

Daily analyses of the Sabatier exhaust gases were made and quantities recorded. Figure 5 shows the results of the activity and provides information relative to the use of these exhaust gases as propellants in a resistojet attitude control system. It should be recognized that the exhaust may include some nitrogen. All nitrogen entering the system is unreacted as it passes through the system and exhausts with any unreacted CO₂.

Operation of the zero-g condenser/separator was not completely initiated until the 14th day of the test; cold Coolanol flow was maintained through the condenser throughout the test, the product condensate being allowed to drain into the backup condenser. When the negative pressure device was energized, it pumped gas through the porous plate of the condenser. Repeated attempts to stop the gas breakthrough were tried on test days 16, 29, 30, and 50.

Efforts included various adjustments in cooling flow. The negative pressure device was actuated 42 times during this period. Replacement of the condenser was delayed to avoid long-term exposure of the crew to any spillage of Coolanol. The condenser was replaced on test day 81. Inspection of the initial condenser indicated discoloration and corrosive pitting of the porous plate, probably caused by hydrogen chloride and hydrogen fluoride resulting from the thermal decomposition of Freon and absorbed in the product water.

The new unit worked in a normal manner until day 83 when the negative pressure device became stuck about a quarter of the way down on the "down" stroke. The negative pressure device had automatically pumped 31 strokes of water at this time. The unit was freed by actuating a momentary switch in parallel with the piston proximity switch. This method of actuating the negative pressure device was used for the remainder of the test. Post-test inspection disclosed that the piston was at the bottom of the stroke, indicating that the piston proximity switch might be inoperative.

Typical operating conditions of the zero-g condenser during the run on the Coolanol side were 38°F inlet and 54°F outlet. The vapor side temperatures were 163°F inlet and 90°F outlet. The unit apparently had inadequate effectiveness to completely remove the water from the exhaust gas.

OPERATION OF TOXIN BURNER

Operation of the toxin burner throughout the test was routine and without operational problems, as previously noted on table 1. Burner temperatures were adjusted between 560°F and 730°F throughout the last 60 days of the test to investigate variations in cooling effect on the Sabatier reactor. The toxin burner was turned off from days 68 through 81 to observe changes in carbon monoxide, methane trace contaminants, and microbiological activity.

On day 68, while turning the toxin unit off, the crew observed a powder deposit in the area of the discharge-to-cabin vent. A sample of this material was collected and passed out for chemical analysis. Preliminary results indicate the material to be mainly chlorides of aluminum, copper, iron, nickel with minor amounts of silicon, magnesium, chromium, titanium, manganese, and boron. It would appear that the material resulted from the thermal decomposition of Freon in the toxin burner to form chlorides and probably fluorides with the Hopcalite catalyst and the stainless steel and aluminum components of the unit. Since this material has an insignificant vapor pressure, it is not known how the material could transport through the regenerative heat exchanger to the vent. Dust carried along with the process gas stream seems the only obvious method.

In light of the catalyst poisoning experience in the Sabatier and the chloride deposits, it can be suspected that the Hopcalite was adversely affected by the Freon. The extent and time history of the catalyst degradation are not known; if the degradation occurred during the initial part of the test, the requirement for a toxin burner can be questioned. If toxin burners are required, methods of protecting the catalyst from poisoning must be developed.

Correlation of carbon monoxide and methane concentrations in the SSS with toxin burner operation is not conclusive. Carbon monoxide is completely oxidized at room temperature by Hopcalite; therefore, correlation with it should be more pronounced. During the period the toxin unit was off, carbon monoxide concentration increased from about 16 to 26 ppm. When the unit was returned to operation, the concentration decreased over a period of 9 days to a level of 18 ppm. This seems to indicate the unit did function to affect the CO level; however, this type of correlation could possibly be expected with an unheated catalyst. The strongest evidence of the ability of the unit to oxidize methane is exhibited during the last 3 days of the test after the repair of the Sabatier exhaust leak. Hydrocarbon concentration at this point reached a level of 60-ppm heptane equivalent, and decreased to a level of 50 ppm at the end of test. Cabin leakage was minimal during this period; therefore, little washout effect of contaminants occurred. This significant lowering in hydrocarbon level tends to indicate the toxin unit maintained some effectiveness throughout the test. However, the general gradual rise in hydrocarbon levels in the atmosphere during the test, which is mainly due to an increase in methane concentration, may indicate that a gradual reduction in capacity was occurring. Daily values of cabin hydrocarbon concentrations are shown in figure 6.

CONCLUSIONS

- A. The Sabatier/toxin burner units performed as expected after catalyst poisoning problems were resolved.
- B. The Sabatier produced twice the weight of it and the toxin burner in water and contributed a considerable amount of thermal energy to support operation of the toxin burner.
- C. Future Sabatier reactor development should include provisions to protect the catalyst from poisons.
- D. Quicker methods of initiating reactor operation such as a glow-plug type starter would be a worthwhile convenience.
- E. Future development of negative pressure devices should tend towards a short-stroke configuration and utilize a separate pumping device to move the water to the storage reservoir.

REFERENCE

1. Perry, John H.: Chemical Engineers' Handbook, Fourth Edition, page 4-12.

TABLE I
MAINTENANCE ACTIVITY

SUBSYSTEM	MAINTENANCE ACTIVITY	SPARES USAGE	HOURS
TOXIN CONTROL	NONE	NONE	NONE
SABATIER	REPLACED FUSE AND PRIMED WATER PUMP	FUSE	1.5
	REPLACED CO ₂ FLOW TRANSDUCER*	TRANSDUCER	0.3
	CLEARED WATER FROM METHANE PUMP*		0.2
	INSTALLED CHARCOAL TRAP IN CO ₂ LINE*	CHARCOAL COLUMN	3.0
	CHANGED CATALYST	CATALYST	7.0
	CHANGED CHARCOAL*	CHARCOAL	2.5
	CHANGED ZERO-G CONDENSER	CONDENSER	1.5
	ATTEMPTED TO UNSTICK NEGATIVE PRESSURE DEVICE		0.6
	REPLACED LEAKING TUBE AT REACTOR OUTLET	12 IN. TUBING	<u>2.0</u>
			18.6

*OUTSIDE ACTIVITY

INTEGRATED SABATIER AND TOXIN CONTROL

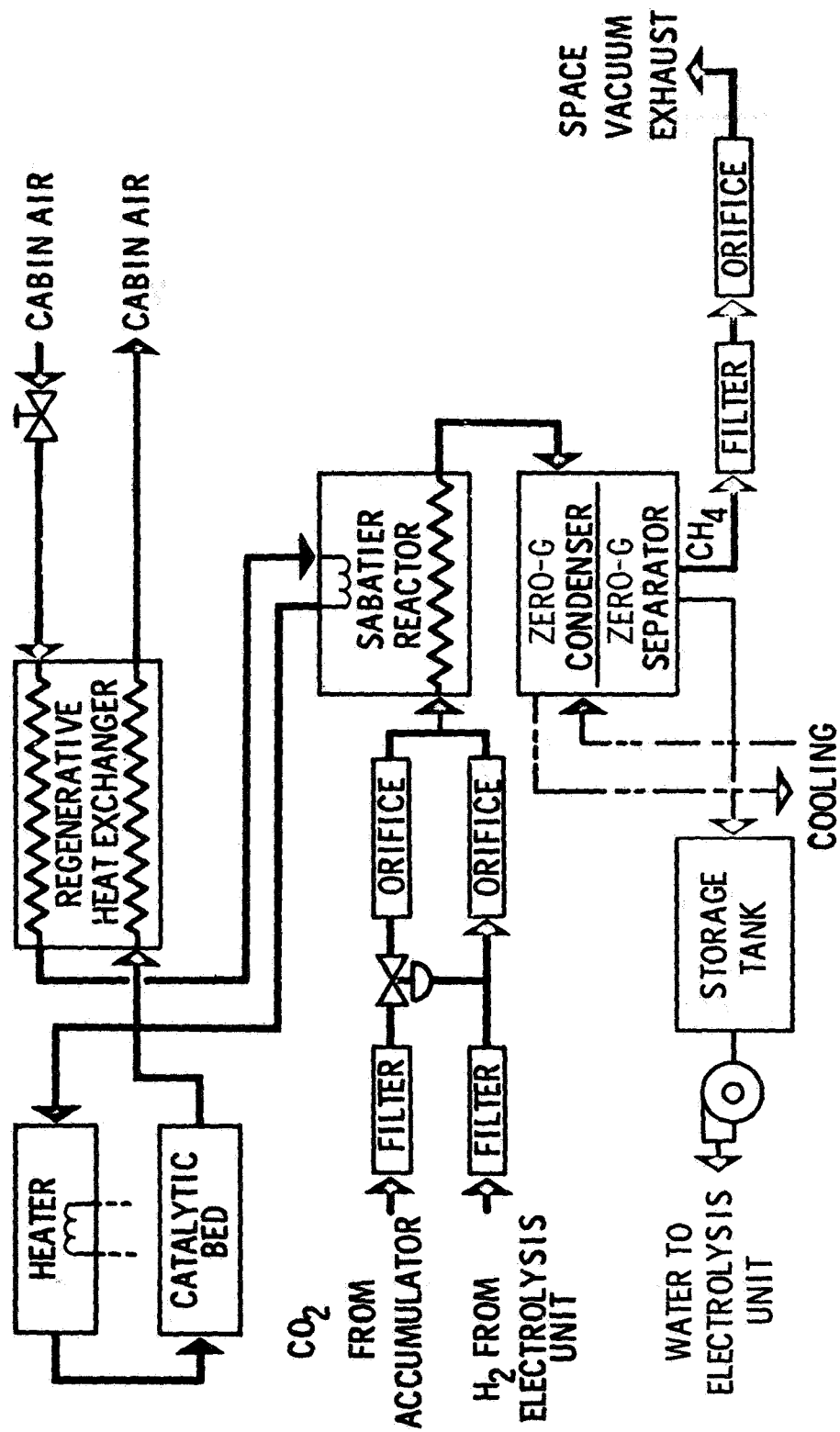


Figure 1

SABATIER WATER PRODUCTION

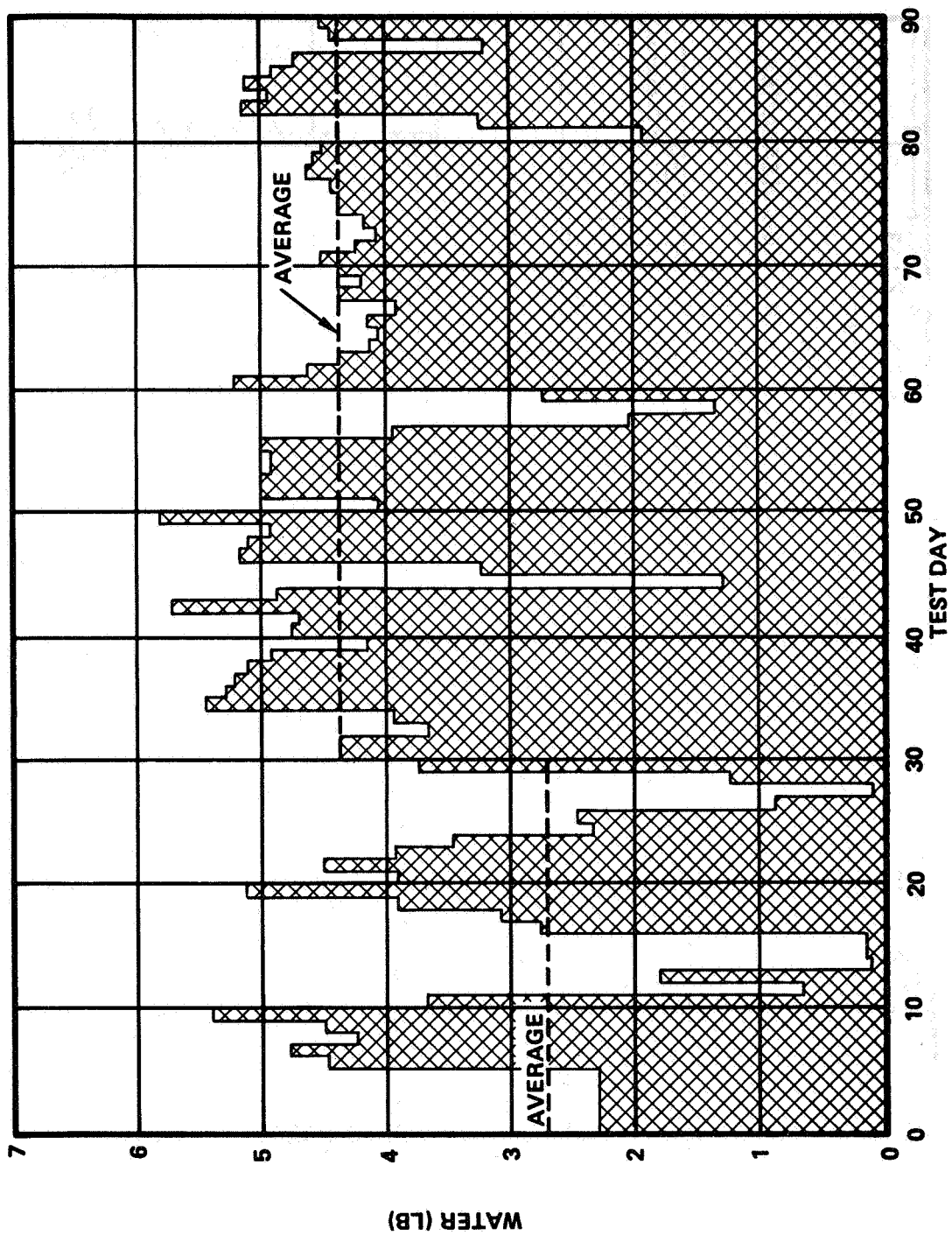


Figure 2

HYDROGEN UTILIZATION

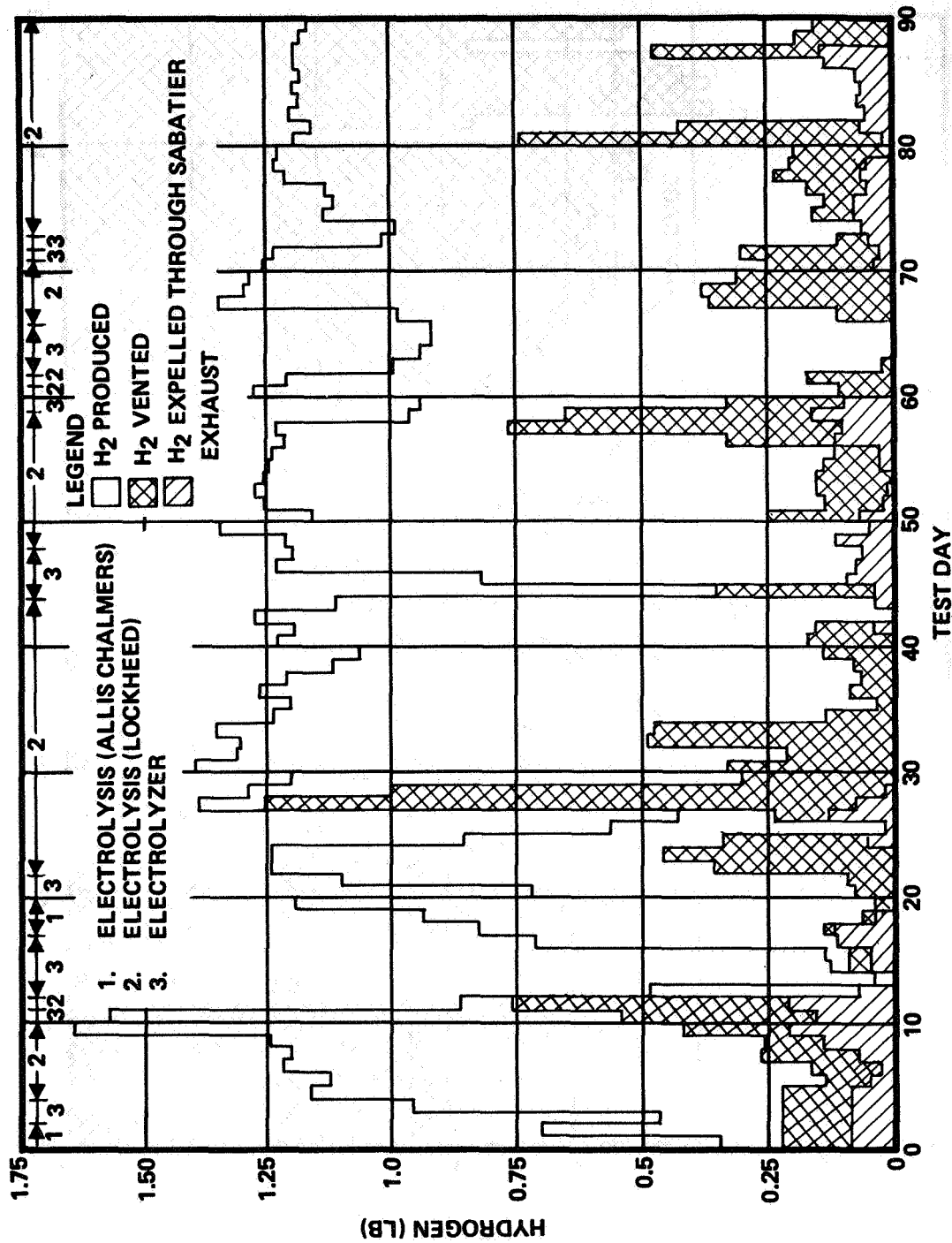


Figure 3

CARBON DIOXIDE UTILIZATION

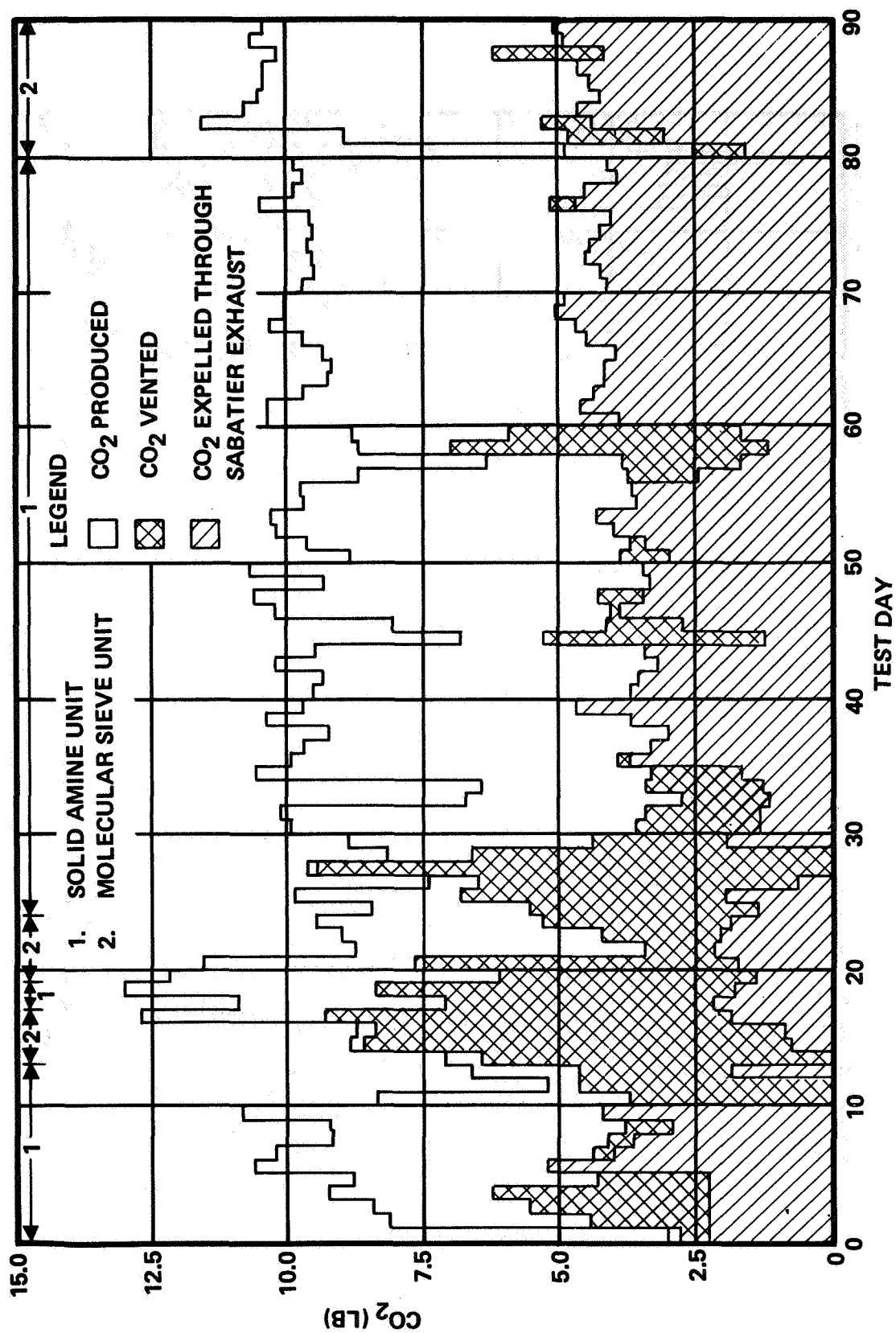


Figure 4

SABATIER EXHAUST PRODUCTS

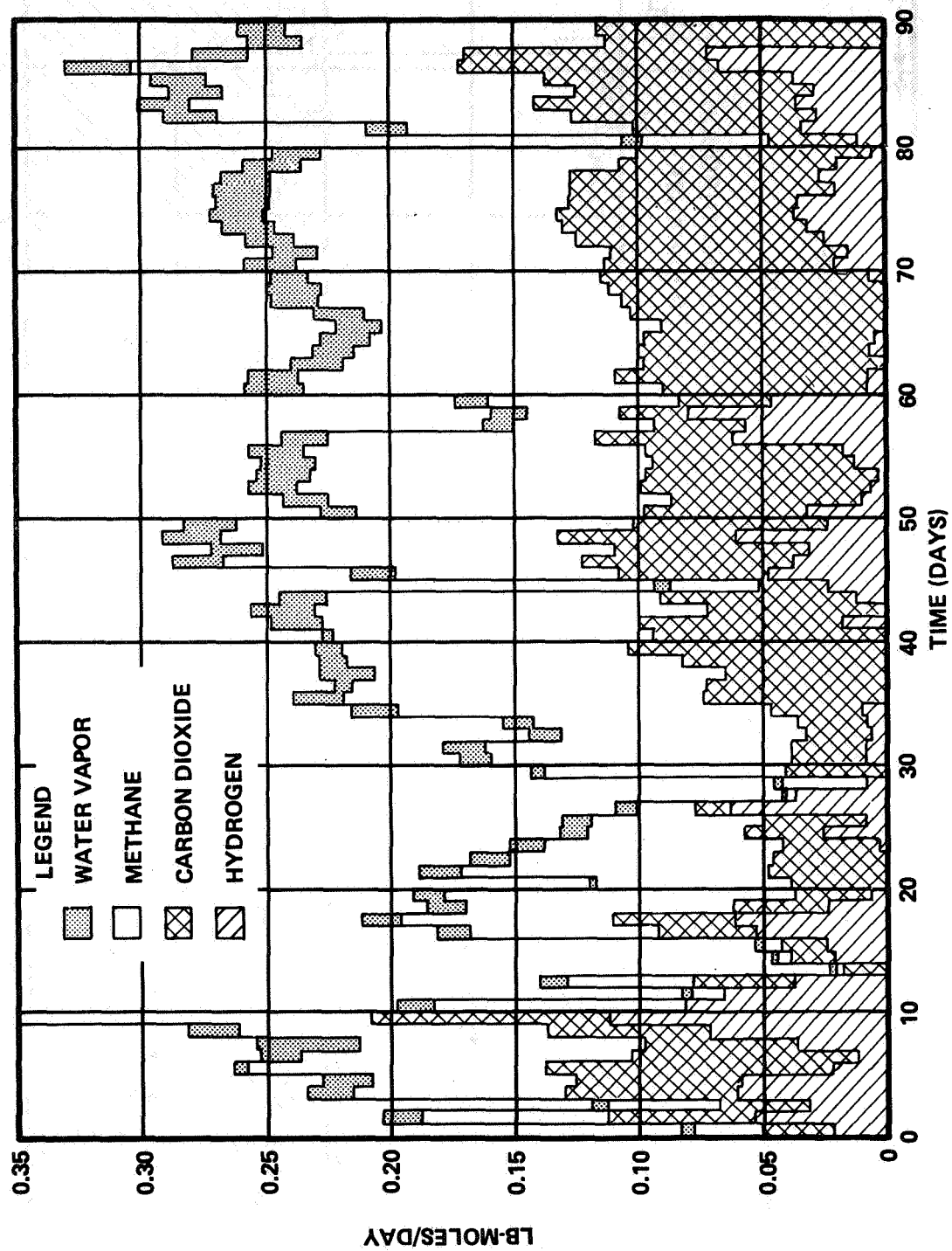


Figure 5

ON-LINE HYDROCARBON ANALYSIS

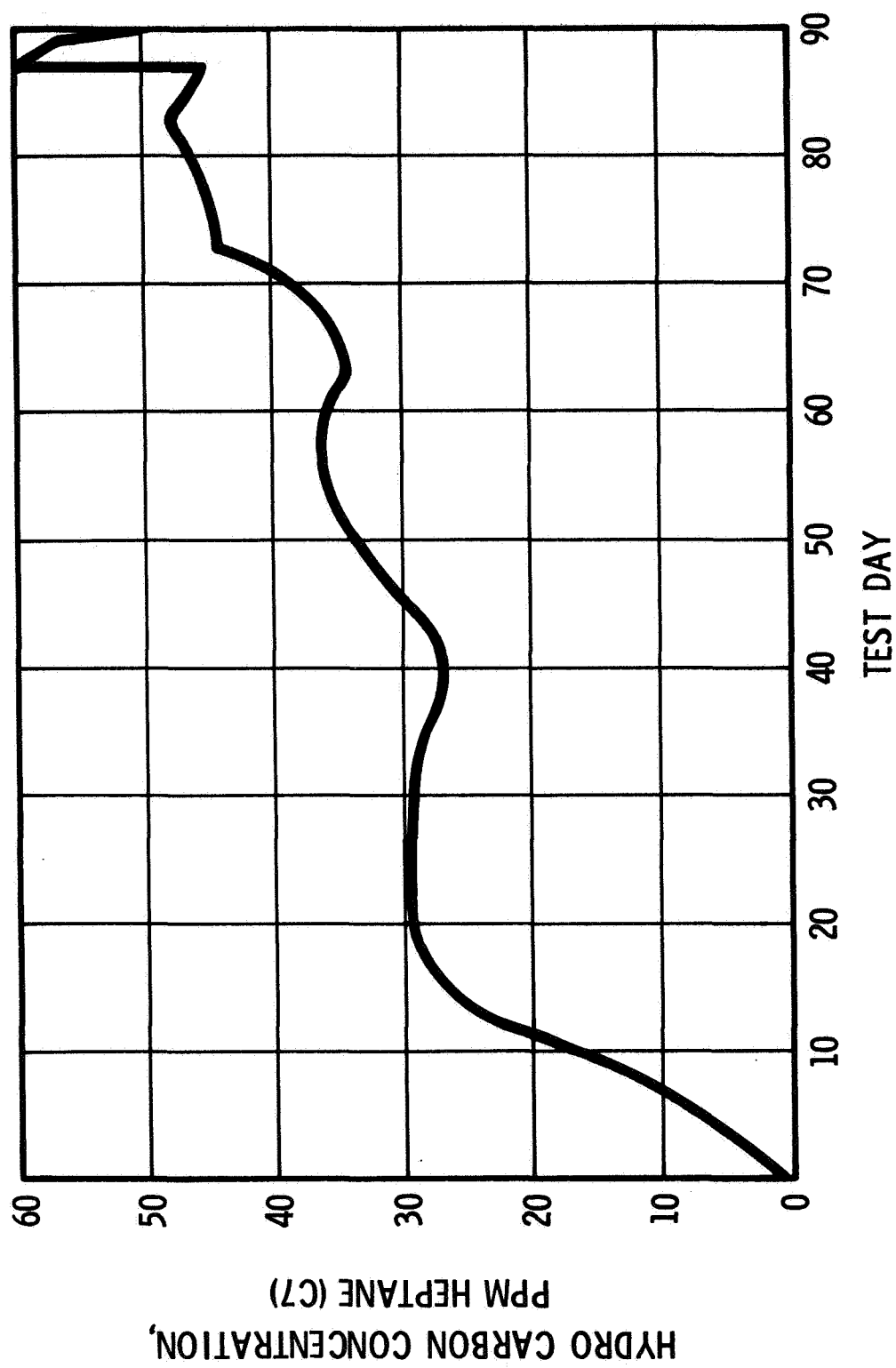


Figure 6

PERFORMANCE OF A SOLID-AMINE CARBON DIOXIDE CONCENTRATOR

DURING A 90-DAY MANNED TEST

By Harlan F. Brose

Hamilton Standard

Division of United Aircraft Corporation

and

Rex B. Martin

NASA Langley Research Center

SUMMARY

A carbon dioxide (CO_2) concentration system which utilized a regenerable amine absorbent was used in the 90-day manned test. Hamilton Standard utilized surplus flight hardware from the Manned Orbiting Laboratory project to meet the cost, schedule, and manned-test constraints. The system design was based on test data provided by MSA Research Corporation. The design provided for limited automatic operation with manned override capability. The successful operation of the unit during the 90-day test establishes solid amine as a feasible CO_2 absorbent with certain advantages over a molecular sieve CO_2 control system. The principal advantages demonstrated in the 90-day test are the ability of the sorbent material to operate with humid influent gas, with good performance at low CO_2 pressures, and with the ability to desorb CO_2 at ambient pressure and higher.

INTRODUCTION

The affinity of Linde Molecular Sieve for water (H_2O) in preference to carbon dioxide (CO_2) is an inherent deficiency of this sorbent when utilized for CO_2 removal since the influent gas must be dehydrated. Consequently, research has been sponsored to investigate sorbents potentially having more desirable characteristics than Molecular Sieve. The MSA Research Corporation (MSA), under contract to the NASA Langley Research Center (LRC) found that the weak-base amine ion-exchange resins showed promise as regenerable CO_2 sorbents. (See ref. 1.) Subsequent research by MSA under contract to LRC derived system-design information specifically for amberlite IR-45 ion-exchange resin from Rohm and Haas Company (ref. 2).

This resin is durable and is widely used in liquid purification processes. It has been found useful in the removal of such weak acids as CO_2 , although relatively little is known about such resins for the absorption of gases. The

earliest references to ion-exchange resins as potential low-concentration CO₂ gas sorbents were for anesthesiology (ref. 3) and submarine atmosphere applications (ref. 4). The resin provides additional advantages over Molecular Sieve in that desorption is at cabin pressure rather than at near vacuum and that elimination of compressors for pumping the CO₂ is potentially possible. The latter aspect will be discussed further herein.

The important characteristics of this sorbent are as follows:

- (1) It is spherical in shape with a mesh size of 16 to 50.
- (2) It has a density of 39 to 43 lb/ft³ with 40- to 45-percent water content and 35- to 40-percent void space.
- (3) The heat capacity when 20-percent H₂O by weight is 0.48 Btu/lb-°F; and the heat capacity when dry is 0.314 Btu/lb-°F.
- (4) It is insoluble and inert in strong acids (except nitric acid), concentrated alkalis, and common organic solvents.
- (5) It is unaffected by prolonged exposure to water at 212° F.
- (6) Porosity, swelling, and moisture-holding properties are dependent primarily upon the degree of polymer cross-linking. Swelling is also directly related to water content.

This steam-desorbed amine sorbent was selected for the CO₂ concentrator system in the advanced integrated life support system study (ref. 5) because of consistently high ratings for the applications considered. Thus, when certain flight-development prototype hardware became available from the Manned Orbiting Laboratory (MOL) in mid-1969 and when the state of amine technology at the time was considered, it was desirable and feasible to have Hamilton Standard design and fabricate an experimental amine sorbent system for the 90-day manned test.

SYSTEM DESCRIPTION

The system design assumed that certain MOL hardware, for example, three canister and valve assemblies, heat exchangers, and so forth, would be available for use in the system. Steam regeneration has several advantages for this sorbent and was planned as the mode of desorption for the system. The most significant advantages are that no heating coils are required in the canisters and that cycling hot and cold coolant is not required. Laboratory investigations were conducted by MSA to determine certain system design- and operation-parameter information specific to the MOL Environmental Control System canister and to this particular three-bed design.

The system design that evolved is shown schematically in figure 1. Three canisters were used in a three-phase cycle which was considered base-line

operation; however, a two-canister mode was also incorporated. In the three-canister mode, each canister is desorbed during one phase or $1/3$ of the cycle and absorbs during two phases or $2/3$ of the cycle. The complete cycle lasts 45 minutes. Each canister is charged with 7.3 pounds of amine containing 15-percent water by weight. A void expansion space, which was 30 percent of the canister volume, was allowed between the top retaining screen and the bed for resin expansion since the resin expands about 1 percent per 1-percent increase in water content up to about 45-percent water by weight, which is the saturation condition of the resin. The water content of the resin cycles between 25 percent by weight at the end of desorption to about 10 percent at the end of absorption.

Process air from the chamber humidity control system at 45°F to 50°F and 40°F dewpoint is passed through either of two redundant fans at $25\text{ ft}^3/\text{min}$ and then through a heat exchanger to condition the air to the desired temperature and relative humidity. The airflow divides and passes through two canisters connected in parallel, where the CO_2 is absorbed by a weak chemical bonding on the amine resin and the purified air is then returned through a second heat exchanger to the cabin. This heat exchanger cools the air and condenses moisture that was removed from the sorbent since the sorbent contains the water condensed from the previous steam desorption.

Each canister undergoes desorption in turn in the following manner: Steam, at cabin pressures, is generated in a two-stage finned-tube-in-shell steam generator. The superheated steam flows into the canister, condenses on the resin, the resin is heated, and the CO_2 is displaced and is reabsorbed downstream. This thermal mass-transfer zone passes through the canister and canister-void-space air, then humid CO_2 and finally steam are eluted from the canister. Since the CO_2 is recovered at 12 psia or higher if desired, the compressor requirements are reduced from those of a molecular sieve system. If an accumulator pressure of 30 psia is acceptable, it would be possible to eliminate compressors completely and use steam pressure to compress the CO_2 into the accumulator. The pressure is limited because IR-45 will degrade at temperatures over about 250°F .

During the first half of the desorption cycle, canister-void-space humid air at about 85°F is flushed from the canister. As CO_2 begins to elute from the bed, a flow-rate change is sensed, and the effluent is diverted to a compressor which stores the CO_2 at a pressure suitable for the oxygen-reclamation system. The effluent temperature rises during this period, and at a temperature of 170°F , the steam breaks through and the flow is diverted back to the system outlet heat exchanger where the gas is cooled and moisture is condensed and returned to the system water accumulator. For redundancy, two compressors are installed in parallel.

Water is recycled within the system, however, a net water loss may occur because of the loss of water vapor in the collected CO_2 and if a net difference exists between the system outlet vapor concentration and the inlet vapor concentration. An external water source was connected to the water accumulator.

The accumulator has high and low level switches which automatically control its refilling.

Two water-metering pumps were installed between the water accumulator and the steam generator. The water-pumping rate was selected so that water would be supplied to the steam generator at a rate sufficient to desorb a canister within the selected desorption period of 15 minutes (1/3 cycle) with about 2 minutes to spare. A back-pressure regulator was located between the effluent diverter valve and the CO₂ compressor to maintain the sorbent bed at the proper pressure to give a steam temperature of about 200° F while CO₂ is being pumped to the accumulator. A second diverter valve was located in the steam line to divert steam to the system condensing heat exchanger after the bed is heated sufficiently to desorb the CO₂ loaded on the bed.

Controls were provided for fully automatic operation for either three- or two-canister operation. For redundancy a completely timed mode of operation was also provided in addition to the flow and temperature controls for desorption. For flexibility during the 90-day test, all control set points were manually adjustable.

Photographs of the front and rear concentrator system are shown in figures 2(a) and 2(b), respectively. The size of the unit is approximately 4 ft x 4 ft x 2 ft. The weight is about 600 pounds. Because of the use of commercial hardware, a frame made of grating to save program schedule and cost, and the fact that the two-canister mode was adequate (as will be discussed later), the size and weight of the concentrator system can be reduced significantly for a flight system.

SAFETY CONSIDERATIONS

System Outgassing

Most materials and parts not approved for use in a manned test with a non-standard atmosphere were enclosed in an aluminum box of 0.060 gauge, spotwelded on five sides. The information displays and controls were mounted on the front of the panel drawer of the box. This entire box assembly and the remaining items containing materials not approved for use in a manned test with a non-standard atmosphere were placed in a 75 ft³ oven, heated to 130° F, and outgassed for three days prior to final system assembly. The hydrocarbon (referenced to pentane) outgassing rate for the three-day period was 18 ppm for the 75 ft³ enclosed space for the first day, 8 ppm for the second day, and 4.5 ppm for the third day.

Sorbent

Four samples of the sorbent were submitted to NASA Manned Spacecraft Center for testing (ref. 6). The results of these tests concerning flash and fire

point, flame-propagation rate, odor, and carbon monoxide (CO) and total-organics outgassing are summarized as follows:

- (1) IR-45 passes flammability criteria
- (2) IR-45 passes odor criteria
- (3) IR-45 passes total-organics criteria
- (4) IR-45 is borderline on CO outgassing, but steam exposure reduces concentrations sufficiently for pass rating

PERFORMANCE PRIOR TO 90-DAY TEST

Testing of a single-canister assembly at MSA indicated that a canister CO₂ loading of up to 2.5 percent of dry-bed weight or 0.15 pound of CO₂ per canister cycle was feasible if a proper water balance could be maintained in the canister. It was known from earlier testing that a 20-percent-by-weight bed water loading was ideal for CO₂ absorption and that higher and lower water loading would give less CO₂ absorption.

Maintaining proper bed water loading was indicated in single-canister testing at MSA as the most important problem in this design, and this fact was confirmed when the system was tested at Hamilton Standard. Thus, if the exact quantity of steam condensed in the bed on desorption and partially absorbed by the bed was not removed or if excessive water was removed during the subsequent drying CO₂ absorption period, the beds would progressively get wetter or dryer, respectively, and less than optimum performance would result. If the beds became slightly wetter each cycle, the CO₂ removal performance would approach zero. If the beds became slightly dryer each cycle, the CO₂ removal rate would stabilize at about 9.6 lb/day at a 4 mm Hg pressure input level with a 30-minute absorption cycle. The optimum removal rate was determined to be about 12 lb/day at an average of 20 percent by weight water loading. As a result, a canister inlet air temperature was selected that would cause the beds to stay on the average on the dry side since only a 9 lb/day CO₂ removal rate was required for the system. Furthermore, the selected temperature of 80° F and 40° F dewpoint gives adequate drying margin to prevent the canisters from becoming wet because of nominal change in coolant flow and inlet air condition.

Absorption performance of the resin is shown in figure 3. These data were taken during the dry, stable operation of the system which resulted in a 9.6 lb/day CO₂ removal capacity. The curve shows the combined absorption of two canisters and the effluent temperature profile of a single canister. It can be seen that most of the CO₂ absorption takes place during the first 10 minutes of its two-phase absorption cycle. However, the remaining 20 minutes are required to complete the bed drying prior to another desorption.

A canister cycling from desorption to absorption is hot and moist but dries rapidly during the first 5 minutes of the absorption cycle because the process-air temperature rises rapidly as it passes through the canister and thus obtains a significant water-vapor capacity. This evaporation cools the bed rapidly and makes drying much slower for the remainder of the cycle. With a given quantity of sorbent, the ratio of bed length to diameter (≈ 2) was unfavorable for an ideal optimization of flow rate and cycle time. The flow rate and cycle time were selected in order to obtain the required capacity; thus, an operation less efficient than would be possible by designing a bed for a specific application resulted.

The desorption characteristics are shown in figure 4. The effluent flow-rate change used as a switch point for CO₂ collection and the steam breakthrough with the corresponding temperature rise indicating completion of CO₂ desorption are evident. The change in effluent flow rate immediately after the diverter valve switches to CO₂ collection results because the back-pressure regulator increases bed pressure.

Approximately 300 hours of investigatory tests were conducted at Hamilton Standard. These tests were concluded by a 3-day continuous operation acceptance test. During the acceptance test, the unit operated fully automatically with no adjustments being made. Average CO₂ performance for the three days was 9.6 lb/day at a 4 mm Hg CO₂ pressure in the air inlet.

Because of the chemical nature of the CO₂ sorption, IR-45 has a more favorable isotherm for low CO₂ pressures than Molecular Sieve. A test was conducted to determine the performance of the system at a 1 mm Hg CO₂ pressure. The system removed 5 lb/day at this condition.

The tests conducted on the amine system for the Langley Research Center and McDonnell Douglas Astronautics Company 90-day test were oriented only to obtain acceptable performance from the system for the four-man crew requirement. Adequate data to determine optimum cycle time, bed geometry, air flow, and so forth, were not possible due to schedule and cost constraints. It appears that significantly greater performance could have been obtained with a shorter cycle (fig. 3) and a ratio of bed length to diameter of about 1 instead of 2, since the bulk of the absorption occurs in the first 10 minutes. It also appeared from these data that two-canister operation may be more desirable. During the 90-day test, it was necessary to operate in a two-canister mode. The performance data verified that the two-canister mode was generally more desirable for this particular system than the three-canister mode.

PERFORMANCE DURING 90-DAY TEST

The amine CO₂ concentrator operated successfully as a system experiment during the 90-day test. This result is evident when the extremely short schedule (8 months) to bring a laboratory concept to prototype manned test hardware is considered. The unit was operated for 71 days. Figure 5 shows the

CO₂ pressure level as a function of test days. The concentrated CO₂ purity during the test was 94 to 98 percent. Table I indicates the malfunctions which did occur during the test and the corrective action taken. For all malfunctions, the crew was able to take corrective action without requiring materials from outside the chamber. From this table, the importance of the attention given to redundancy and alternate operating modes in the design of the unit is apparent.

TABLE I.- MALFUNCTIONS OF AMINE CO₂ CONCENTRATOR DURING 90-DAY TEST

Test days	Malfunction	Cause	Corrective action
3 to 10, 81	Bed 1 rotary valve sticking when repositioning porting for absorb	Excessive friction between rotary-valve plate and seals	Lubricating plate and manual operation not successful; finally went to two-bed operation
24, 81	Unit operating temperatures 15° F higher than the indicated readings	Unit thermocouple reference-junction set point had changed	Compensated for discrepancies between actual and indicated temperatures
29, 62, 64, 66, 67, 71, 72, 73	Water accumulator dry or overflowing	Water-supply solenoid valve sticking in both the open and close positions	Cycled with panel override switch; finally replaced solenoid valve
48, 58, 60, 63, 75, 77, 79	Condenser drain line plugged	Deposits of material in line	Periodically purging the line with pressurized nitrogen (N ₂)
60	Noise in compressor 1	Unknown	Switched to compressor 2
71	28-volt "power on" light not energized (unit running)	Burned-out bulb	Replaced bulb
74, 80	Amine material and steam leaking from hole in bed 3	Epoxied patch loosened	Plugged hole (amine material not replaced)
34	Fan would not start	Unknown	Switched to fan 2

A complete posttest analysis of the unit will be conducted. In addition to the analysis of the malfunctioning components and an analysis of materials compatibility, a postacceptance test will be conducted to determine the amine material condition.

Periodic manual adjustment of coolant flow to the unit was required during the test. For flight hardware or new long-duration test hardware, fully automatic control of airflow and inlet-drying conditions should be incorporated. A direct measure of bed-moisture conditions is necessary in order to properly control inlet process-air drying capacity, and this improvement must be considered in future hardware.

Information derived during the 90-day test and from a posttest analysis of the hardware will greatly enhance the capability of designing a solid-amine CO₂ concentrator for future manned tests.

CONCLUDING REMARKS

The use of existing flight-development hardware provided the lead time necessary to fabricate a system suitable for the 90-day test; however, this hardware posed some problems in its adaptation to the amine-system design. A more favorable canister configuration would have resulted in a reduced steam flow rate and a significant increase in the absorption efficiency. As a result of the 90-day test, it is obvious that direct sensing of the sorbent moisture condition is mandatory and that this information should be used to control the drying capacity of the inlet process air automatically. In addition, ion-exchange cleanup in the water and steam circuit is needed and may show a very significant trace-contaminant-removal capability for this system. The use of waste or isotope heat is felt to be significantly advantageous with this system concept.

All malfunctions of the system that occurred in the 90-day test were hardware development problems that are judged to be amenable to a reasonable development effort. Perhaps the problem that may require the most development and testing is the hardware design to "hold" the sorbent during cyclic swelling and contracting without causing sorbent agglomeration.

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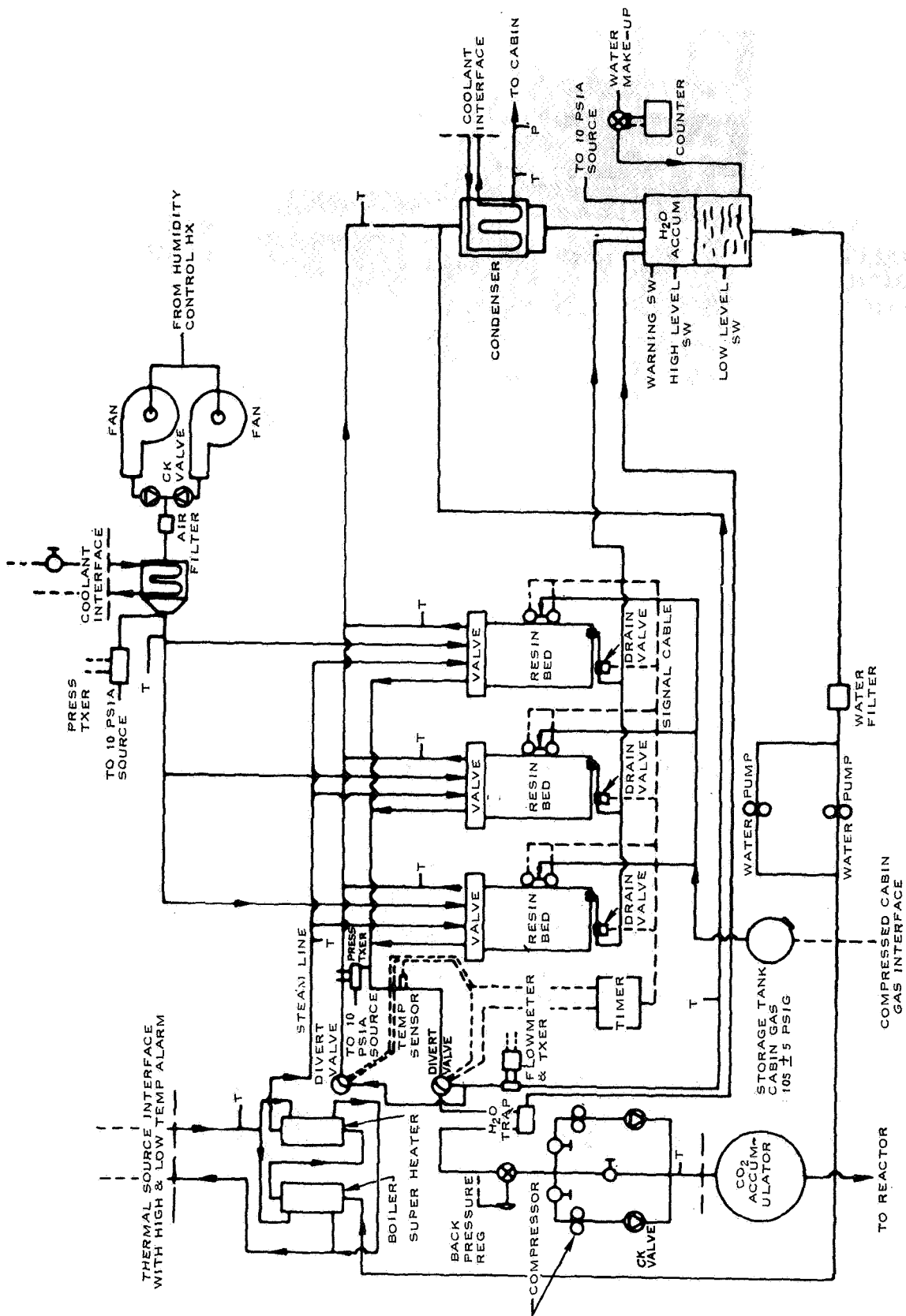
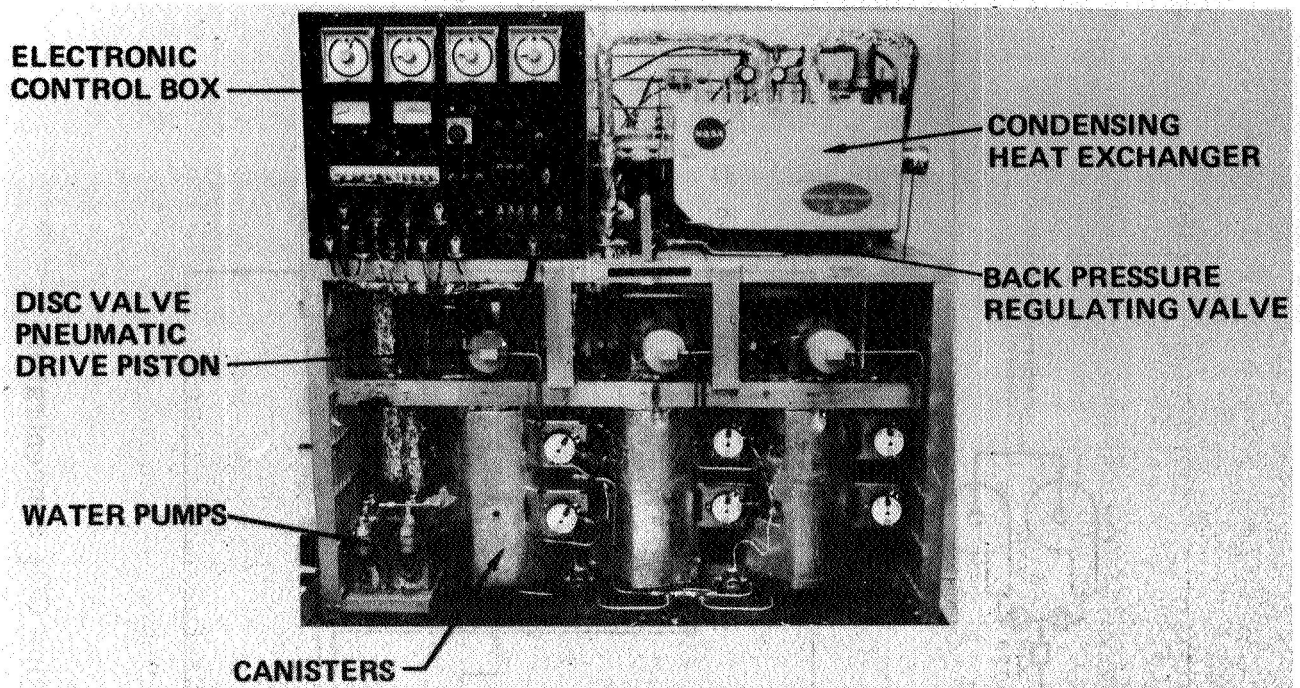
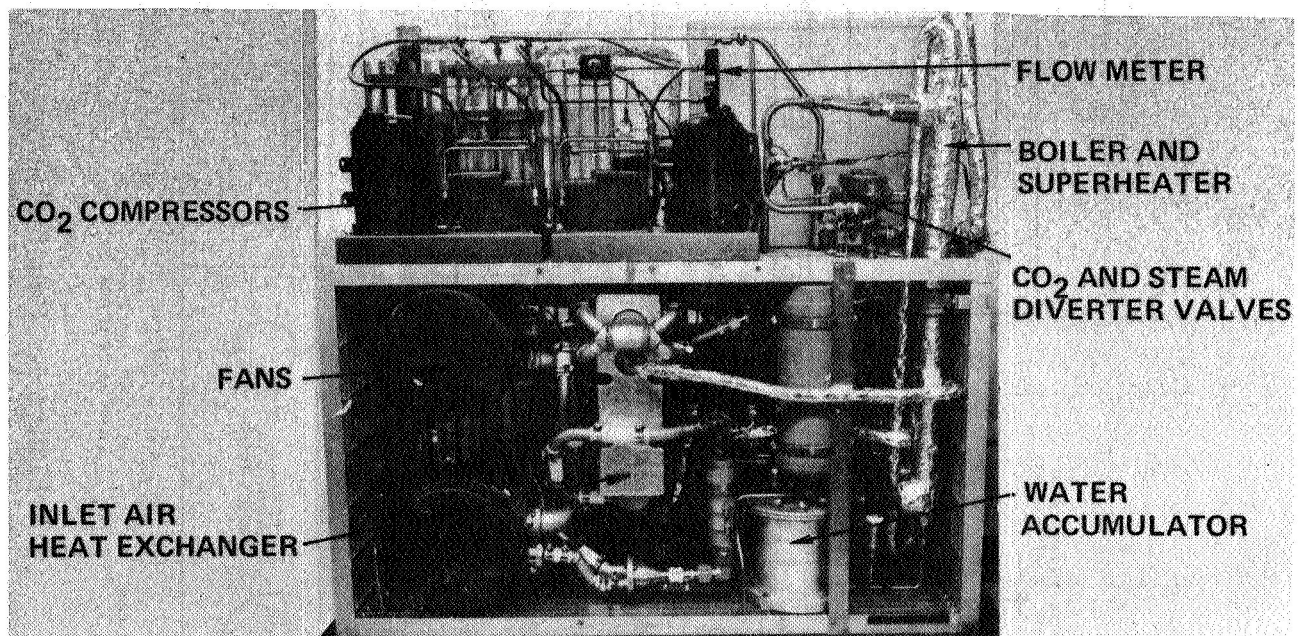


Figure 1.- Schematic drawing of the amine CO₂ concentrator.



(a) Front view.



(b) Rear view.

Figure 2.- Amine CO₂ concentrator.

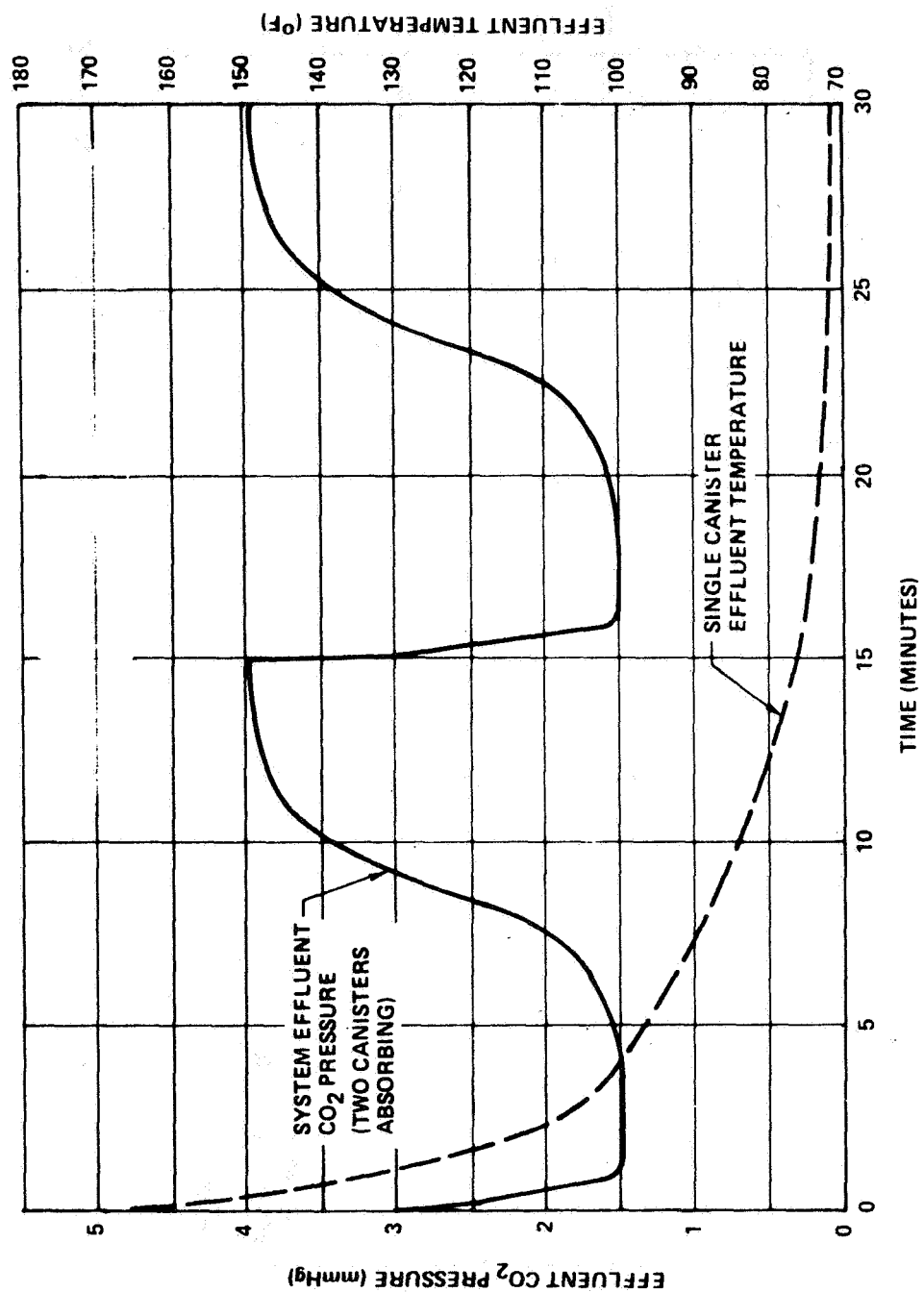


Figure 3.- Amine absorption profile. Three-canister operation with 30-minute absorb cycle and 15-minute desorb cycle.

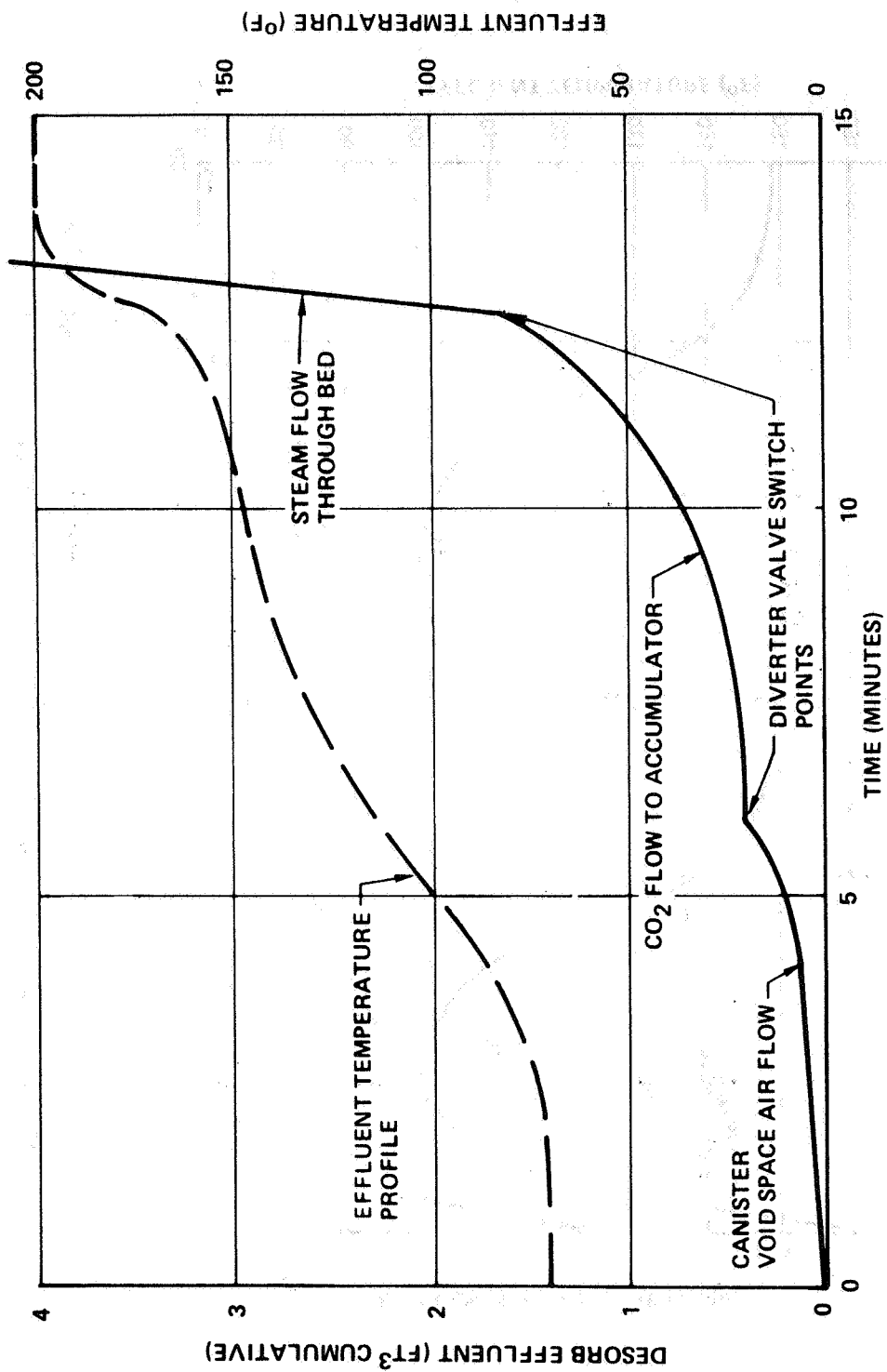


Figure 4.- Amine desorption profile. Steam flow, 6.7 lb/hr; amine weight, 6.3 pounds dry.

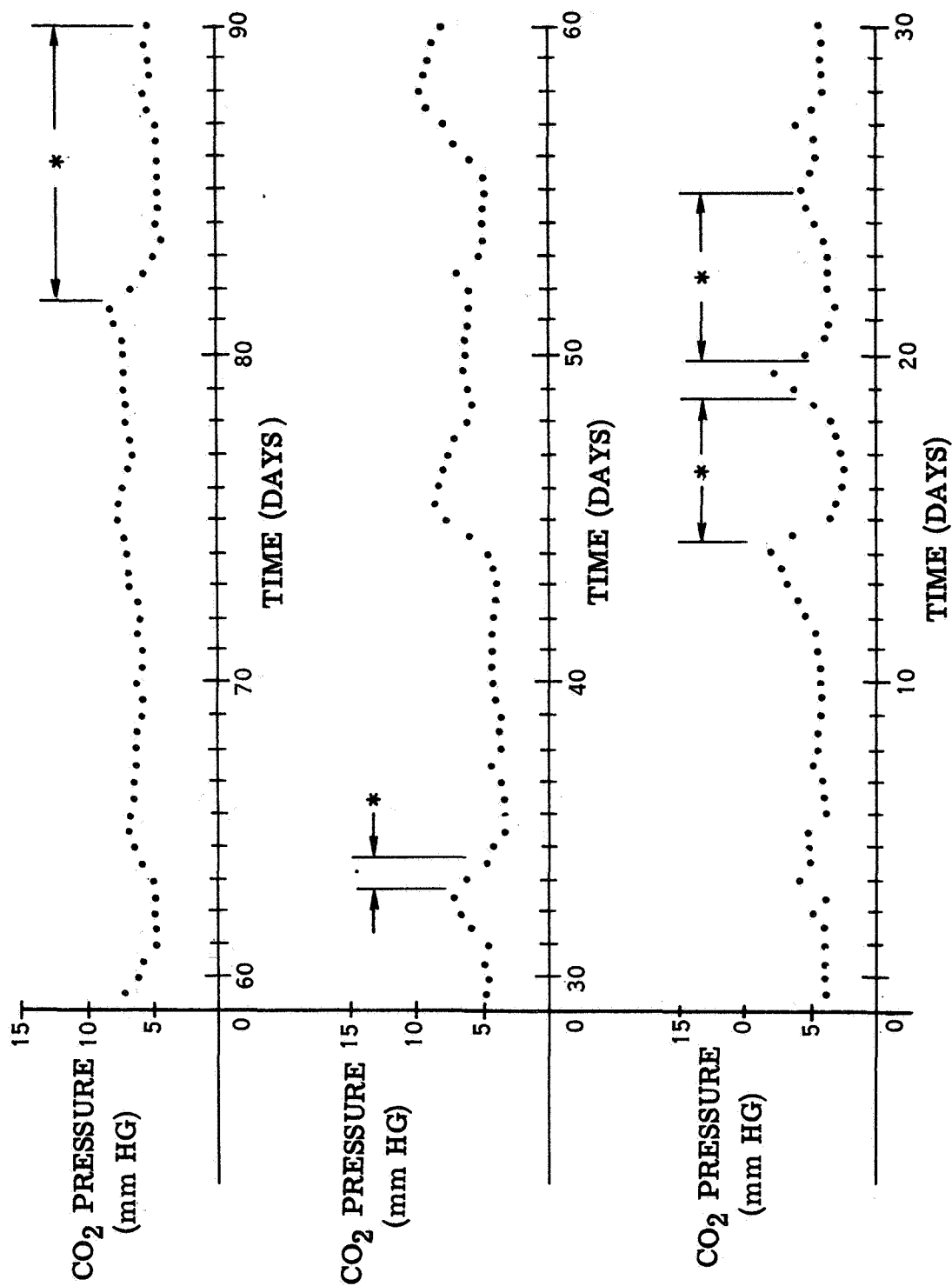


Figure 5.- Ninety-day test performance of the amine CO₂ concentrator. (* indicates that molecular sieve backup was used.)

ANALYSIS OF TRACE CONTAMINANTS

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SUMMARY

Analysis of atmospheric samples for the presence of trace contaminants was conducted by MDAC to ensure the continued health and safety of the test crew. Analysis was done by chromatograph on direct samples and concentrated samples obtained by freeze-out techniques to determine the presence of organic compounds. The direct samples indicated the presence of as many as nine organic contaminants although none were present at levels approaching critical values. The concentrated samples, taken weekly, indicated as many as 23 compounds, most of which occurred at very low levels. Major trace contaminants included methane, as high as 290 ppm at the end of the run; carbon monoxide, which varied from 10 to 27 ppm; and Freon TF, which reached peak values as high as 11.6 ppm. Methane and carbon monoxide are most probably the metabolic products of the crewmen. The Freon TF is a cleaning solvent which was used before the test, apparently leaving residuals that maintained the cabin concentration throughout the test.

Inorganic compounds were measured by wet chemical analysis on samples taken daily. Compounds detected included total aldehydes, which maintained a fairly stable concentration of about 0.35 ppm during the test, and ammonia during some periods, reaching levels of 2 to 3 ppm. During toxin burner operation, the presence of ammonia was frequently accompanied by trace amounts of oxides of nitrogen (about 0.1 ppm). Sulfur dioxide, hydrocyanic acid, hydrogen sulfide, chlorine, hydrochloric acid, and phosgene were tested for and not found at any time during the test.

Tests run on CO₂ removed from the cabin by the molecular sieve and solid amine units indicated increased concentration of Freon TF over the cabin levels. This resulted in locating an activated carbon filter in the CO₂ line to remove this contaminant during the test.

Tests on catalyst from the Sabatier reactor and a white powder found at the outlet of the toxin burner indicated heavy concentrations of halogens. This apparently resulted from catalytic decomposition of the Freon TF and may have caused a significant loss in catalyst effectiveness in both units.

INTRODUCTION

During the 90-day operation of the Space Station Simulator (SSS) and the short-duration manned and unmanned test runs which preceded it, analytical support was provided by determining the composition and daily fluctuations of trace contaminants. A daily search was instituted in which representative

air samples were withdrawn from the SSS and analyzed. Both sampling and analytical procedures depended on whether the tests pertained to organic or inorganic compounds.

Additional analyses carried out by the laboratory pertained to:

- A. Composition of constituents in CO₂ gases between concentrator and Sabatier unit.
- B. Analysis of Sabatier catalyst and toxin burner catalysts.
- C. Purity of hydrogen, oxygen, and CO₂ tanks.
- D. Composition of exit vapors of the Sabatier reactor.
- E. Analysis of reclaimed water for compliance with potability standards proposed by the Ad Hoc Committee of the Space Science Board of the National Research Council.

The present report describes the types and quantities of inorganic and organic compounds found in the SSS and the analyses of toxin burner and Sabatier catalysts.

Particular attention was directed to specific compounds (see table 1), which have been reviewed and to which pretest planning had assigned contingency and abort levels. Many of these levels were established upon the recommendation of the Panel on Air Standards for Manned Space Flights of the National Academy of Science.

INORGANIC CONTAMINANTS

Conventional wet chemical analyses of the cabin air were performed daily for ammonia, sulfur dioxide, oxides of nitrogen, and aldehydes. Twice a week tests were run for hydrocyanic acid, hydrogen sulfide, chlorine, hydrochloric acid, and phosgene. These test data as well as those obtained during the 4-day unmanned and the 5-day manned tests which preceded the 90-day test are tabulated in tables 2 and 3.

During the 90-day manned operation of the SSS, the VD-VF unit and the wick evaporator system were alternately used for water recovery. It was desired to obtain data on the effect of the open-loop wick evaporator on the normal contaminant level measured in the cabin air, and whether a correlation existed between the observed contaminants such as ammonia and oxides of nitrogen. Additionally, information was desired on the effects of the toxin control unit on formation and buildup of contaminants in the SSS.

During the unmanned and manned test periods preceding the 90-day test, the space cabin air was almost free of contaminants. Analyses conducted after the start of the 90-day test also showed the absence of all inorganic compounds, as seen in table 3, with the only exception being the aldehydes which started

with a low value of 0.04 ppm, and soon increased to 0.2 to 0.4 ppm. They remained at this level throughout the entire test. Initially, neither ammonia nor oxides of nitrogen were detected in the cabin air, regardless whether the VD-VF or wick evaporator system was in operation. This lasted until test day 52, when the presence of ammonia was detected at about 0.5 ppm. Simultaneously with the appearance of ammonia, traces of oxides of nitrogen (less than 0.1 ppm) were found. This reinforces a previous indication that the catalytic burner may cause oxidation of ammonia to oxides of nitrogen.

On test day 57, after the wick evaporator had been in operation for 12 days, the further feeding of the wick was stopped, and the VD-VF unit was placed in operation. In spite of this, the ammonia concentration in the chamber increased during the following few days, reaching a peak at about 2.8 ppm. This may be due to the fact that after starting to dry the wick, more ammonia was formed from the wick deposits and released into the cabin air. After several days without wick operation, the ammonia concentration in the atmosphere returned to zero.

The effects of the toxin control unit with regard to the ammonia conversion can be seen from the data of test days 68 through 82. During this time, the unit was inoperative. In this entire period no oxides of nitrogen were found in the SSS although the amount of ammonia that was present in the cabin atmosphere was similar to the previous period. Soon after the toxin burner was activated, the oxides of nitrogen again appeared, reaching a maximum of about 0.15 ppm.

ORGANIC CONTAMINANTS

Daily gas samples were withdrawn from the cabin air by the syringe and needle technique. Analyses were carried out with the two gas chromatographs calibrated for 120 organic compounds at two temperatures and with two column packing materials. Ten organic compounds including carbon monoxide (which was measured with a Lira Infrared Analyzer) were identified and quantitatively determined. Figures 1 through 5 show the identification and concentrations of these compounds for each test day. The concentration ranges were: Freon TF, 1.6 to 11.6 ppm; acetone, 0.06 to 2.39 ppm; toluene, 0.05 to 0.15 ppm; ethyl alcohol, 0.35 to 1.49 ppm; dichloroethane, 0.08 to 0.25 ppm; methyl ethylketone, 0.05 to 0.27 ppm; 2-ethylbutanol, 0.14 to 0.43 ppm; 2-ethyl hexanol, 0.1 to 0.68 ppm; methane, 110 to 290 ppm; and carbon monoxide, 7 to 27 ppm.

The horizontal bar between test days 68 and 82 represents the time interval during which the toxin burner was not in operation. After test day 68, the carbon monoxide level (fig. 5) increased from about 16 to 26 ppm. When the toxin burner was reactivated, the level was gradually reduced to 17 ppm at the end of the test.

With regard to methane (fig. 5), it was noted that the concentration of this hydrocarbon increased from approximately 160 to 245 ppm when the toxin burner was inoperative. However, no decrease in the methane level

was observed when the toxin burner was placed in operation again. A further increase resulted between samples taken on days 87 and 88. This was caused by a leak in the exhaust line of the Sabatier reactor which vented exhaust gases into the cabin, thereby adding to the methane level in the cabin air, since the methane concentration in the exhaust was approximately 50 percent. Replacement of the faulty tube stopped this venting and the corresponding rise in methane level.

With regard to the other organic compounds plotted in figures 1 through 4, no specific trends were noticeable. Measured concentrations were relatively low in all cases.

Freeze-out samples were collected on a weekly basis by passing 60 liters of cabin air into a stainless steel trap which was immersed in liquid nitrogen. The noncondensable gases were returned to the cabin, while the remainder was condensed in the stainless steel trap and was analyzed by chromatograph. A total of 23 organic compounds could be identified by the use of the concentrated samples, as compared to nine compounds when noncondensed samples were used.

Most of the chromatographic peaks exhibited by the large-volume samples could be identified. Those from the pre-test checkout runs are shown on table 4 and from the 90 day test on tables 5 and 6. A few unassigned minor peaks remain to be identified. Efforts in this direction are being undertaken.

It may be of interest that three compounds, methylisobutylketone, n-amylalcohol, and n-valeraldehyde, were present only during the unmanned 5-day run. These compounds were not found during any of the manned runs.

ANALYSIS OF CARBON DIOXIDE

The carbon dioxide desorbed from molecular sieve or solid amine sorbant after removal from the SSS atmosphere was then processed in the Sabatier reactor.

Since the CO₂ originated in the cabin air the possibility existed that other contaminants may be present in the CO₂ stream leaving the concentrator. It was important to know the composition of the gas stream reaching the Sabatier unit because the catalyst, upon which the Sabatier reaction is based, may be gradually deactivated or completely destroyed by the presence of undesirable contaminants.

Analysis of the CO₂ showed the presence of Freon TF at an average concentration of 8.0 ppm, and acetone and ethyl alcohol at low concentrations. Carbon dioxide, oxygen, and nitrogen comprised 98 to 100 percent of the total gas flow.

An analysis of the Sabatier catalyst, which consists mainly of metallic nickel deposited on kieselgur as carrier, was carried out. This sample was removed from the reactor by the crew on test day 29 and passed out of the chamber after a long period of intermittent operation had led to the conclusion

that catalytic activity had been lost. It was found to contain large amounts of chlorides and fluorides. Although there were no samples of unused catalyst available, it is probable that the identified halogens came from the Freon TF present in the CO₂ initially supplied to the reactor. Comparisons between unused and spent catalyst will be made. The efficiency of the catalyst may have been impaired or completely destroyed by continuous contact with halogens from the Freon TF.

A metal analysis of the catalyst by atomic adsorption showed nickel and silicon as major components. Present in trace amounts were boron, phosphorus, manganese, iron, magnesium, and lead. These elements may be assumed to be normally present in the catalyst.

After the test crew replaced the spent nickel catalyst with new material on test day 29, an activated carbon filter was placed in the CO₂ line. Analyses of samples taken downstream of the carbon filter showed that Freon TF as well as the two organic compounds mentioned above had been completely removed. This point was subsequently monitored periodically for the balance of the test and the carbon filter replaced to prevent further contamination of the catalyst by Freon.

A white powder at the outlet of the toxin burner was collected at the end of the test. Analysis of this powder showed an extremely high concentration of chlorides. The presence of fluoride was not specifically identified because it was obscured by the high chloride content. Analysis of the powder by atomic adsorption spectroscopy showed the following major constituents: iron, aluminum, nickel, and copper, besides several minor trace constituents. These major metallic constituents may have originated in the Hopcalite catalyst or from attack of the tubing or heat exchanger downstream of the catalyst bed.

TABLE I
MAJOR ATMOSPHERIC CONTAMINANTS IN SSS

CONTAMINANT	ACCURACY	NORMAL OPERATIONS	LOWER END OF CONTINGENCY OPERATIONS	ABORT LEVEL	ALLOWABLE LEVEL SPECIFIED BY NAS/NRC COMMITTEE
CO (ppm)	±2.0	12.0	100	200	X
CO ₂ (mm Hg)	±0.4	4.0	8	*	
HYDROCARBONS (ppm)	±2.0	4.0	60	300	
NH ₃ (ppm)	±1.0	4.0	75	150	
ALDEHYDES (ppm)	±0.005	1.0	15	25	
SO ₂ (ppm)	±0.25	0.5	7	12	
H ₂ S (ppm)	±1.0	1.0	15	30	
(NO) _x (ppm NO ₂)	±0.1	0.5	1.5	15	
O ₃ (ppm)	±0.001	0.03	0.15	1.5	
CHLORINE (ppm)	±0.04	0.1	0.7	1.5	
CYANIDES (ppm)	±1.0	1.0	3.0	15	
PHOSGENE (ppm)	±0.2	0.07	0.15	1.5	
ETHANOL (ppm)	±0.2	2.5	300	1,500	
TOLUENE (ppm)	±0.2	0.5	30	300	
2-ETHYL BUTANOL (ppm)	±0.2	1.0	20	60	
N-BUTANOL	±0.2	1.0	15	150	X
2-BUTANONE	±0.2	2.0	30	300	X
CHLOROFORM	±0.2	0.5	7	70	X
DICHLOROMETHANE	±0.2	2.5	40	700	X
DIOXANE	±0.2	1.0	15	150	X
ETHYLACETATE	±0.2	4.0	60	600	X
2-METHYLBUTANONE	±0.2	2.0	30	300	X
TRICHLOROETHYLENE	±0.2	1.0	15	150	X
1,1,2-TRICHLORO; 1,2,2-TRIFLUOROETHANE AND RELATED CONGENERS	±0.2	20	150	1,500	X
FORMALDEHYDE	---	0.05	0.15	3.0	X
DICHLOROLACETYLENE	---	0	DETECTED	0.1	X
VINYLDIENE CHLORIDE	---	2.0	10	25	X

* > 60 (3 MIN), 60 TO 40 (10 MIN), 40 TO 30 (30 MIN), 30 TO 20 (60 MIN), 20 TO 15 (48 HOURS)

TABLE 2
ATMOSPHERIC CONTAMINANTS

DATE	NH ₃	NO ₂	SO ₂	ALDEHYDES	HCN	H ₂ S	Cl ₂	HCl	PHOSGENE
(ALL VALUES IN PARTS PER MILLION)									
UNMANNED 4-DAY TEST									
4/24/70	0.0	0.0	0.0	--					
4/25	0.0	0.0	0.0	--					
4/26	0.0	0.0	0.0						
4/27	0.0	0.0	0.0	0.24					
4/28	0.0	0.0	0.0	0.067					
MANNED 5-DAY TEST									
4/29	0.0	0.0	0.0	0.12					
4/30	0.0	0.0	0.0	0.18	0.0	0.0	0.0	0.0	0.0
5/1/70	0.0	0.0	0.0	0.11					
5/2	0.0	0.0	0.0	0.25					
5/3	0.0	0.0	0.0	--					
5/4	0.0	0.0	0.0	0.06	0.0	0.0	0.0	0.0	0.0

TABLE 3

ATMOSPHERIC TRACE CONTAMINANTS DURING 90-DAY TEST

DATE	TEST DAY	NH ₃	SO ₂	NO ₂	ALDEHYDES	HCN	H ₂ S	Cl ₂	HCl	PHOS-GENE
6/13	1	0	0	0	0.04	0	0			
6/14	2	0	0	0	0.35	0	0			
6/15	3	0	0	-	0.32	0	0	0	0	0
6/16	4	0	0	0	0.27					
6/17	5	0	0	0	0.25					
6/18	6	0	0	0	0.27	0	0	0	0	0
6/19	7	0	0	0	0.33					
6/20	8	0	0	0	0.27					
6/21	9	0	0	0	0.27					
6/22	10	0	0	0	0.28	0	0	0	0	0
6/23	11	0	0	0	0.25					
6/24	12	0	0	0	0.31					
6/25	13	0	0	0	0.29	0	0	0	0	0
6/26	14	0	0	0	0.35					
6/27	15	0	0	0	0.27					
6/28	16	0	0	0	0.30					
6/29	17	0	0	0	0.27	0	0	0	0	0
6/30	18	0	0	0	0.26					
7/1	19	0	0	0	0.27					
7/2	20	0	0	0	0.47	0	0	0	0	0
7/3	21	0	0	0	0.33					
7/4	22	0	0	0	0.38					
7/5	23	0	0	0	0.24					
7/6	24	0	0	0	0.38	0	0	0	0	0
7/7	25	0	0	0	0.31					
7/8	26	0	0	0	0.33					
7/9	27	0	0	0	0.34	0	0	0	0	0
7/10	28	0	0	0	0.32					
7/11	29	0	0	0	0.34					
7/12	30	0	0	0	0.32					
7/13	31	0	0	0	0.33	0	0	0	0	0
7/14	32	0	0	0	0.33					
7/15	33	0	0	0	0.34					
7/16	34	0	0	0	0.33	0	0	0	0	0
7/17	35	0	0	0	0.34					
7/18	36	0	0	0	0.34					
7/19	37	0	0	0	0.31					
7/20	38	0	0	0	0.35	0	0	0	0	0
7/21	39	0	0	0	0.31					
7/22	40	0	0	0	0.28					
7/23	41	0	0	0	0.29	0	0	0	0	0
7/24	42	0	0	0	0.34					
7/25	43	0	0	0	0.23					
7/26	44	0	0	0	0.23					
7/27	45	0	0	0	0.27	0	0	0	0	0

TABLE 3 - Concluded

DATE	TEST DAY	NH ₃	SO ₂	NO ₂	ALDE-HYDES	HCN	H ₂ S	Cl ₂	HCl	PHOS-GENE	ALL VALUES IN PARTS PER MILLION
7/28	46	0	0	0	0.31						
7/29	47	0	0	0	0.30						
7/30	48	0	0	0	0.28	0	0	0	0	0	
7/31	49	0	0	0	0.32						
8/1	50	0	0	0	0.25						
8/2	51	0	0	0	0.29						
8/3	52	0.5	0	tr	0.31	0	0	0	0	0	
8/4	53	0.5	0	tr	0.34						
8/5	54	0.5	0	tr	0.34						
8/6	55	0.5	0	tr	0.34	0	0	0	0	0	8/8 STOPPED FEEDING WICK
8/7	56	0.5	0	tr	0.35						8/9 AFTER STARTING TO DRY WICK,
8/8	57	0.5	0	tr	0.33						MORE NH ₃ FORMED FROM WICK
8/9	58	2.8	0	tr	0.33						DEPOSITS AND WAS RELEASED
8/10	59	1.9	0	0.1	0.32	0	0	0	0	0	INTO CABIN AIR
8/11	60	2.8	0	0.1	0.30						8/11 CORRELATION BETWEEN
8/12	61	0.5	0	tr	0.33						NH ₃ AND (NO) _x
8/13	62	0	0	0	0.32						
8/14	63	0	0	0	0.33						
8/15	64	0	0	0	0.25						
8/16	65	0	0	0	0.26						
8/17	66	tr	0	0	0.30	0	0	0	0	0	8/19 TOXIN BURNER TURNED OFF
8/18	67	1.4	0	0	0.31						
8/19	68	1.9	0	0	0.25						8/19 WICK EVAPORATOR PRE-
8/20	69	2.4	0	0	0.33	0	0	0	0	0	HEATER LEFT ON SINCE
8/21	70	1.4	0	0	0.31						PREVIOUS USE OF WICK
8/22	71	1.3	0	0	0.33						EVAPORATOR WAS TURNED
8/23	72	tr	0	0	0.34						OFF LAST NIGHT
8/24	73	tr	0	0	0.35	0	0	0	0	0	8/21 FLOOR WAS WASHED WITH
8/25	74	0	0	0	0.37						CO ₂ CONDENSATE WATER
8/26	75	tr	-	-	0.38						FROM SOLID AMINE
8/27	76	1.3	0	0	0.39	0	0	0	0	0	
8/28	77	1.6	0	0	0.39						
8/29	78	1.8	0	0	0.30						
8/30	79	1.3	0	0	0.27						
8/31	80	1.6	0	0	0.23	0	0	0	0	0	
9/1	81	1.8	0	0	0.32						9/1 SOLID AMINE SYSTEM
9/2	82	1.8	0	0	0.31						DISCONTINUED
9/3	83	1.8	0	0	0.38	0	0	0	0	0	9/1 MOLECULAR SIEVE STARTED
9/4	84	1.1	0	0	0.39						9/1 WICK EVAPORATOR
9/5	85	1.8	0	0	0.39						STARTED
9/6	86	1.8	0	0	0.39						9/1 VD-VF DISCONTINUED
9/7	87	3.5	0	0.15	0.42						9/2 TOXIN BURNER BURNED ON
9/8	88	4.0	0	0.12	0.41	0	0	0	0	0	HOLE IN SABATIER EXHAUST LINE
9/9	89	1.8	0	tr	0.43						
9/10	90	0.5	0	tr	-	0	0				

TABLE 4
CONSTITUENTS OF FREEZE-OUT SAMPLES

	UNMANNED 5-DAY 4-28-70	SECOND DAY OF 5-DAY MANNED 5-1-70	FIFTH DAY OF 5-DAY MANNED 5-4-70
FREON TF	●	●	●
TOLUENE	●	1	●
ACETONE	●	●	●
ETHYL ALCOHOL	1	●	●
2-ETHYL BUTANOL	●	●	●
2-ETHYL HEXANOL	●	1	●
CYCLO-HEXANE	1	1	1
ETHYLENE DICHLORIDE	1	1	1
MEK	●	1	●
CHLOROFORM	1	1	1
M-XYLENE	1	1	1

	UNMANNED 5-DAY 4-28-70	SECOND DAY OF 5-DAY MANNED 5-1-70	FIFTH DAY OF 5-DAY MANNED 5-4-70
2,2, DIMETHYL BUTANE	●	●	●
BUTYL ALCOHOL	●	●	●
METHYL ALCOHOL	●	●	●
DICHLORO METHANE	●	●	●
HEPTANE	●	●	●
ISOPROPYL ALCOHOL	●	●	●
P-XYLENE	●	●	●
O-XYLENE	●	●	●
METHYLISOBUTYL KETONE	●	●	●
N-AMYLALCOHOL	●	●	●
N-VALERALDEHYDE	●	●	●
ISOMYLALCOHOL	●	●	●

NOTE: ● PRESENT -- NOT FOUND SAMPLE VOLUME: 60 LITERS

TABLE 5
CONSTITUENTS OF WEEKLY FREEZE-OUT SAMPLES

DATE	TEST DAY	FREON TF	TOLUENE	ACETONE	ETHYL ALCOHOL	2-ETHYL BUTANOL	2-ETHYL HEXANOL	CYCLO- HEXANE	ETHYLENE DICHLORIDE	MEK	CHLOROFORM	M-XYLENE
6-15-70	3	•	•	•	•	•	•	•	•	•	•	•
6-23	11	•	•	•	•	•	•	•	•	•	•	•
6-30	18	•	•	•	•	•	•	•	•	•	•	•
7-7	25	•	•	•	•	•	•	•	•	•	•	•
7-14	32	•	•	•	•	•	•	•	•	•	•	•
7-21	39	•	•	•	•	•	•	•	•	•	•	•
7-28	46	•	•	•	•	•	•	•	•	•	•	•
8-5	54	•	•	•	•	•	•	•	•	•	•	•
8-11	60	•	•	•	•	•	•	•	•	•	•	•
8-18	67	•	•	•	•	•	•	•	•	•	•	•
8-25	74	•	•	•	•	•	•	•	•	•	•	•
9-1	81	•	•	•	•	•	•	•	•	•	•	•
9-8	88	•	•	•	•	•	•	•	•	•	•	•

NOTE: • PRESENT - NOT FOUND SAMPLE VOLUME: 60 LITERS

TABLE 6
CONSTITUENTS OF WEEKLY FREEZE-OUT SAMPLES

DATE	TEST DAY	2,2 DIMETHYL- BUTANE	BUTYL ALCOHOL	METHYL ALCOHOL	DICHLORO METHANE	HEPTANE	ISOPROPYL ALCOHOL	P-XYLENE	O-XYLENE	METHYL ISOBUTYL KETONE	N-AMYL ALCOHOL	N-VALERALDEHYDE	ISOAMYL ALCOHOL
6-15-70	3	•	•	•	•	•	•	•	•	•	•	•	•
6-23	11	•	•	•	•	•	•	•	•	•	•	•	•
6-30	18	•	•	•	•	•	•	•	•	•	•	•	•
7-7	25	•	•	•	•	•	•	•	•	•	•	•	•
7-14	32	•	•	•	•	•	•	•	•	•	•	•	•
7-21	39	•	•	•	•	•	•	•	•	•	•	•	•
7-28	46	•	•	•	•	•	•	•	•	•	•	•	•
8-5	54	•	•	•	•	•	•	•	•	•	•	•	•
8-11	60	•	•	•	•	•	•	•	•	•	•	•	•
8-18	67	•	•	•	•	•	•	•	•	•	•	•	•
8-25	74	•	•	•	•	•	•	•	•	•	•	•	•
9-1	81	•	•	•	•	•	•	•	•	•	•	•	•
9-8	88	•	•	•	•	•	•	•	•	•	•	•	•

NOTE: • PRESENT - NOT FOUND SAMPLE VOLUME: 60 LITERS

FREON TF AND ACETONE CONCENTRATION

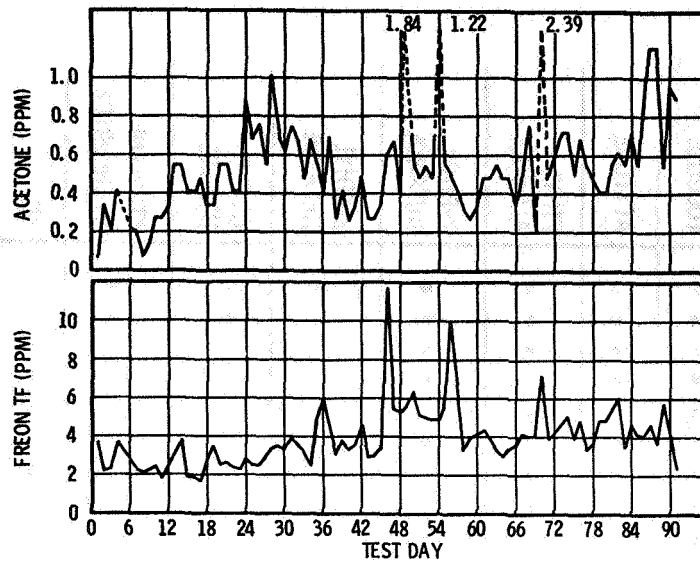


Figure 1

ATMOSPHERIC TRACE CONTAMINANTS IN 90-DAY TEST

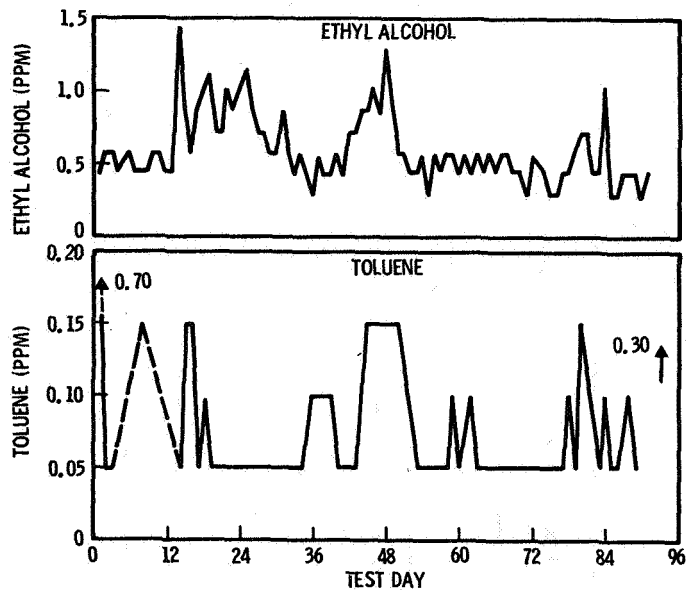


Figure 2

ATMOSPHERIC TRACE CONTAMINANTS IN 90-DAY TEST

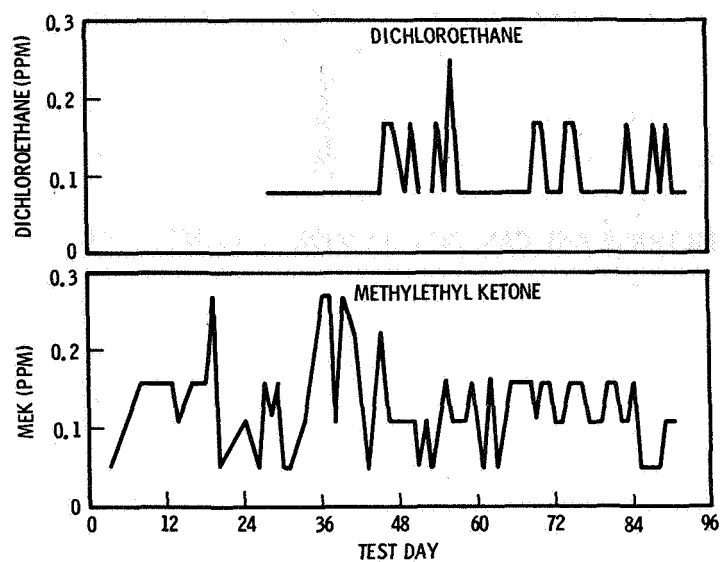


Figure 3

ATMOSPHERIC TRACE CONTAMINANTS IN 90-DAY TEST

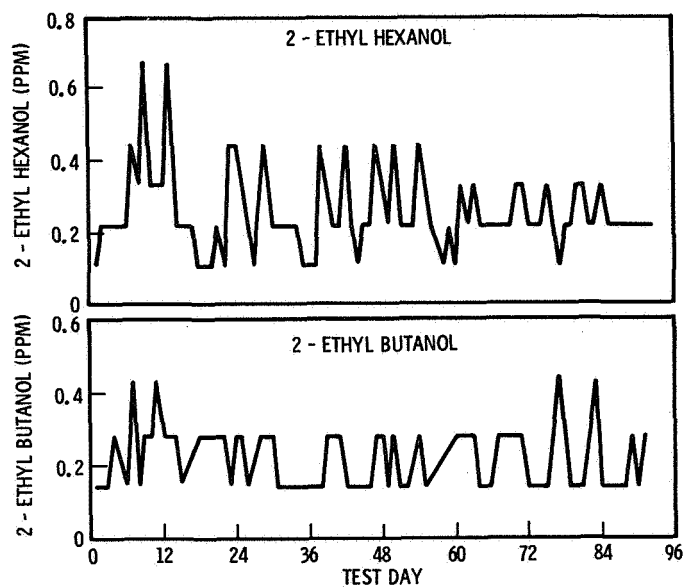


Figure 4

METHANE AND CARBON MONOXIDE CONCENTRATION

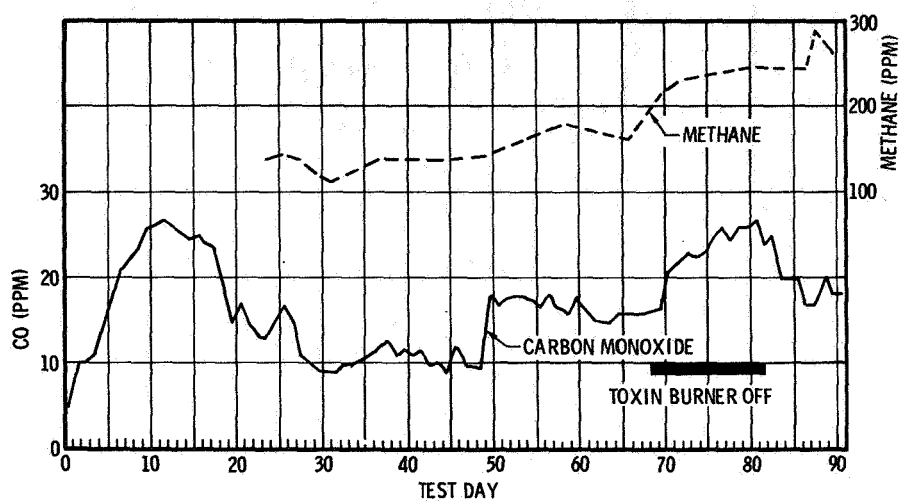


Figure 5

MEASUREMENT OF TRACE ATMOSPHERIC CONSTITUENTS IN THE 90-DAY SPACE STATION SIMULATOR

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ABSTRACT

The significant analytical data and methods of collecting trace atmospheric components found during the 90-day manned space chamber test are reviewed. The three collection methods and special sampler used on this program provided samples for measuring the major, minor, and trace components with classical gas volumetric analytical precision throughout the dynamic range and with reasonable turnaround time. Approximately 100 components were identified and quantitatively measured using gas chromatography, mass spectrometry, infrared spectrophotometry, and high-vacuum rack manipulation. With relatively few exceptions (and some minor test difficulties) the SSS atmosphere was found to be of higher quality than the average troposphere. It is believed that these data will also serve as a base for parametric auto-instrumentation.

INTRODUCTION

The purpose of this program was to measure the trace atmospheric constituents found in the Space Station Simulator and expediently report these data to the technical monitor for medical surveillance. This information was also used to verify automatic instrumental monitoring of selected components. During this study more than 100 compounds were identified and quantitatively measured using state-of-the-art gas chromatographic and mass spectrometric techniques.

SAMPLING

Three methods of sample collection were employed using the general procedure shown in Figure 1. The credence of all chemical analytical data depends on the reliability of sampling. For this reason principally, and in addition to the inherent weaknesses in any single known sampling method, three accepted procedures were used. These were charcoal adsorption, cryogenic sample collection, and direct or "grab" sampling. As shown, the activated charcoal system was arranged for parallel or serial collection with the direct and cryogenic system. For this program a sample of the chamber atmosphere was continually directed through one of the collection modes. A pictorial view of the complete sampler is shown in Figure 2. This sampler, though modified to accept the charcoal system, was used earlier for the Apollo 7, 8, and LEM atmospheric

studies. It is the property of the Langley Research Center (fabricated by the Atlantic Research Corporation). Figure 2(b), a side view of the sampler, shows three charcoal adsorption tubes serially arranged to remove trace constituents from the chamber gas stream.

Each adsorption tube contained approximately 100 g of Barnebey-Cheney AC charcoal. Before use the charcoal was thermal-vacuum treated and periodically examined as an analytical sample to assure the program that no contaminant would be added to the chamber and that each sample would represent only the components collected from the chamber. The cryogenic system consists of four stainless steel collection cylinders each having a capacity of 500 ml. The first trap was operated slightly below 0° C, the 2nd at -80° C, and the third and fourth at the boiling point of liquid nitrogen (approximately -190° C). Grab samples were taken with cylinders similar to the ones used for cryogenic collection.

Gas flow for this collection system is shown in Figure 3. Two Diapumps, manufactured by Air Controls, Inc., were used to move and return the chamber atmosphere through the collection system. This system offered independent flow control from the Gas Analysis Console pumps, a desired redundancy. Gas flow rates for the cryogenic system, corrected to 760 torr pressure, were varied downward from approximately 1000 to 750 cc/min in an attempt to improve collection efficiency. Differences in amount collected between the adsorption and cryogenic systems are discussed later. With the sample collection system and flow chart shown, a continuous surveillance of the chamber atmosphere was maintained. The schedule for each collection method was varied somewhat to accommodate special analytical requests of the technical monitor. This variation was minimal however and Figure 4 shows the schedule used for the middle month of the program. A total of 25 grab samples, 28 cryogenic sample sets, and 28 charcoal collections were taken during the course of the test. Periodic checks on gas flow (measured with Matheson Mass Flow Meters) were made by McDonnell Douglas personnel when the Aerojet team was off site.

ANALYTICAL METHODOLOGY

The samples were removed from the sampler, brought to the Laboratories, analytically divided into 3 fractions and analyzed generally within a 24 hour period. Occasionally, special analyses were made in the same 8 hour period of sampling when some question of atmospheric contamination was suspected. Each sample was handled on the laboratory high-vacuum system shown in Figure 5. This equipment, which included the metal system on the other side of the rack, was maintained at pressures below 10^{-5} torr when not employed for sample manipulation. Periodic blank samples were analyzed to assure the analyst that the data generated from the test sample was not biased from equipment contamination. Cleanliness of the sample cylinders was also verified by this periodic spot testing.

Each charcoal trap was transferred in an inert atmosphere box to a 200 ml round bottom flask and attached to the vacuum system as shown in Figure 6. The

flask was temperature programmed from ambient to 170° C at a rate approximating 10° C/min. The effluent was directed through -80° C U-traps and two special Schultz traps shown in the upper right side of Figure 5. After 1 hour of desorption, the products were transferred to receiving flasks for analysis. The total system is fitted with Fischer-Porter teflon high-vacuum stopcocks.

The direct atmosphere and cryogenically collected samples were split into equal fractions, by alternately using vacuum and helium pressurization, using the system schematically shown in Figure 7. Each was uniformly expanded into 3 evacuated receivers, the sample cylinder purged with helium (if required) and this product added to the receiver manifold. All connecting systems, sample cylinders and receivers were maintained at 80° C. After each sample split, the system was vacuum thermally cycled 3 times to insure cleanliness for the following runs.

The major analytical tool supporting this study was the instrument complex gas chromatography-mass spectrometry. Figure 8 shows the F&M Model 5756 Chromatograph fitted with flame ionization, electron capture, and thermal conductivity detectors each separately recorded, and an Infotronics HS11 integrator coupled to the FID mode. The sample inlet system, constructed by the laboratories, is fitted with packless bellows valves. The arrangement is such that with the sample fraction attached, the connecting tube, sample loop and a portion of the inlet system can be evacuated and helium purged while under a controlled temperature of 100° C. Figure 9 illustrates the sample flow. The instrument is fitted with a Porapak Q and a Carbowax 1000 column. These are operated alternately, one analyzing and the second backflushing. Flow direction is controlled with Circle Seal valves located within the column oven. The column effluent is directed to the detectors in the approximate percentages shown: 63 to FID, 2 to ECD, 25 to TCD and 10 to the mass spectrometer.

The Consolidated 21-104 mass spectrometer (MS), shown in Figure 10, is attached to the chromatograph with a short heated line. This line is directed to the analyzer input where a portion of the sample enters and the remainder is removed through a second vacuum system. While the laboratory has identified this inlet system as "a direct in-line inlet" the introduction to the analyzer resembles a Ryhage venturi. Spacing of the column effluent line to the analyzer inlet opening is somewhat critical and optimum response is achieved through experimental positioning. Other capabilities of the MS used on this program include a total ion monitor and special sweep selectors for monitoring selected m/e ranges. The latter was used for following three particular components, ammonia 17, formaldehyde 30, and sulfur dioxide 64 amu. Finally, a number of special measurements were made using infrared spectrophotometry and a long-path gas cell. The data obtained from these measurements were in agreement with separate MS measurements.

ANALYTICAL DATA

The analytical data acquired on this program are too massive to be conveniently reported here. However, I will try to present significant observations on selected data, compare the collection systems on the basis of material

recovery, and show a typical chromatogram. Very significant increases in chamber atmosphere contamination during the 90-day period were not observed. Presumably the "clean air" condition was directly related to the chamber air purification system. On one occasion the Laboratory had the opportunity of examining several charcoal samples from the Wick Evaporator. These data were interesting in that halogenated materials (e.g., freons, halogenated unsaturated hydrocarbons, methyl chloroform types) and low-boiling hydrocarbons showed extensive penetration while the higher boiling hydrocarbons and oxygenated materials generally were collected on the first layers of charcoal. For example, Freon 113 showed a bed penetration in terms of $\mu\text{g/g}$ charcoal of 1070 at the inlet, 1690 at the center, and 3280 at the exit of the purifier. Analyses of the new charcoal was $3.0 \mu\text{g/g}$. Methyl acetylene and methyl chloroform increased 16 fold and trifluorochloroethylene 30 fold. Conversely, acetone and methyl alcohol decreased by a factor of 5. These data might suggest a reason for the atmospheric compositional variations occurring during the 90-day study. Total product recovery was examined from the three collection methods. These data indicate that direct sample collection appears to provide the greatest calculated contaminant concentrations although signal responses were quite low in most cases. Cryogenic sampling provided a concentration factor from 50 to 100 times, while the quantity of gas sampled with charcoal was from 300 to 2000 times that of the grab sample. Considering the dynamic range of compound concentrations and quantity of gas sampled (10^8) the observed disparities might not be considered too serious. A comparison of the cryogenic and adsorption data are shown in Figure 11. Let us examine these data for a moment. Excluding water, carbon dioxide, Freon 113, and the major atmospheric components, the values shown represent the remaining total collected material. Flow rates through the charcoal started at 1 liter/min were reduced to 750 cc/min, to 300 cc/min, and finally to a rate near 100 cc/min in an attempt to attain recoveries approaching those of the cryogenic system. Likewise, cryogenic collection was made for the first 3 sets at 1 liter/min, decreased to 750 cc/min and finally (the last 2 sets) to approximately 500 cc/min. It is suggested that differences in the data obtained from these methods were, in part, due to elution of the adsorbents (with H_2O and CO_2) or deactivation of the charcoal. On addition of a drying agent and later lithium hydroxide plus Drierite after day 36 as a pretreatment column for the adsorption system, a marked improvement in recovery was observed. Either proposed mechanism could substantially reduce the amount of minor constituents adsorbed by a given amount of charcoal. A portion of this study is continuing under NASA Contract NAS 9-11049.

The change in observed concentration of several constituents was followed throughout the 90-day test. These data are shown in Figure 12. While this figure is a little too "busy," some observations can be abstracted from it. First, Freon 113 quantities are shown for all three collection systems. Differences between direct and cryogenic sampling generally remain the same throughout, e.g., a factor of 2., except for a few perturbations. The charcoal recovery was improved by predrying the gas stream although recoveries were never equivalent. Recall for a moment the information obtained on the Wick evaporator charcoal; the halogenated hydrocarbons were poorly retained or easily desorbed. Trifluorochloroethylene (TFCE), shown on the charcoal graph, is an impurity in the Freon 113 solvents or a degradation product of one of the freons. Its concentration varies rather consistently with Freon 113 at about 10% of the

latter. Benzene, a material with a relatively high adsorption isotherm, showed a generally increasing trend throughout the test. Even with benzene a measurable increase was observed after water was removed from the atmospheric gas stream.

Acetaldehyde and isoprene, two known human exudates, were followed through the test. A general concentration buildup was expected but did not materialize. This may be related to their relative chemical instabilities. Finally, ethylbenzene and isopropyl alcohol (IPA) were followed on the direct sample data sheets. With the exception of 2 or 3 samplings, a generally increasing level for IPA would indicate a decreasing capacity of the purification system. If the large charcoal scrubber reached a saturation level for organics, however, large changes would have been observed for all organics. Ethylbenzene varied rather randomly during the test.

Figure 13 illustrates the generally increasing trend of contaminant buildup. Note that one of the sample containers used for the 57 day cryogenic collection had faulty valves. This failure was not observed until after the sample set was taken. Freon 113 data was omitted from this figure because rather enormous concentration variations were observed and the general trend in all other products would have been obscured. Figure 14 shows the chromatograms of 2 selected samples. As mentioned earlier, two chromatographic columns were used for every sample. A 12-ft by 1/8-in. Porapak Q column was temperature programmed from 30° to 150° C at a rate of 4 degrees/min. Most of the low boiling hydrocarbons and halogenated materials were resolved on this column. After approximately 60 minutes of operation this column was backflushed and a second split sample introduced into a 20-ft by 1/8-in. Carbowax 1000 (10% on Gas Chrom Q) column. This column was programmed from 30° to 150° C at a rate of 4 degrees/min and run for approximately 45 minutes. Arrows from one chromatogram to another illustrate the complimentary nature of both columns and the increased analytical capability that is achieved with duo-column operation. Each of these columns were operated with a matched column used for equalizing flow rate and providing a stable baseline.

A number of other experiments were conducted for the program. These included measuring total water recovery for the project, following the level of methane, carbon monoxide and hydrogen with IR and MS, analyzing several breath samples taken in teflon cylinders and analyzing coolanol for its impurities, stability, and decomposition products under thermal and oxidative degradation simulating chamber spill conditions.

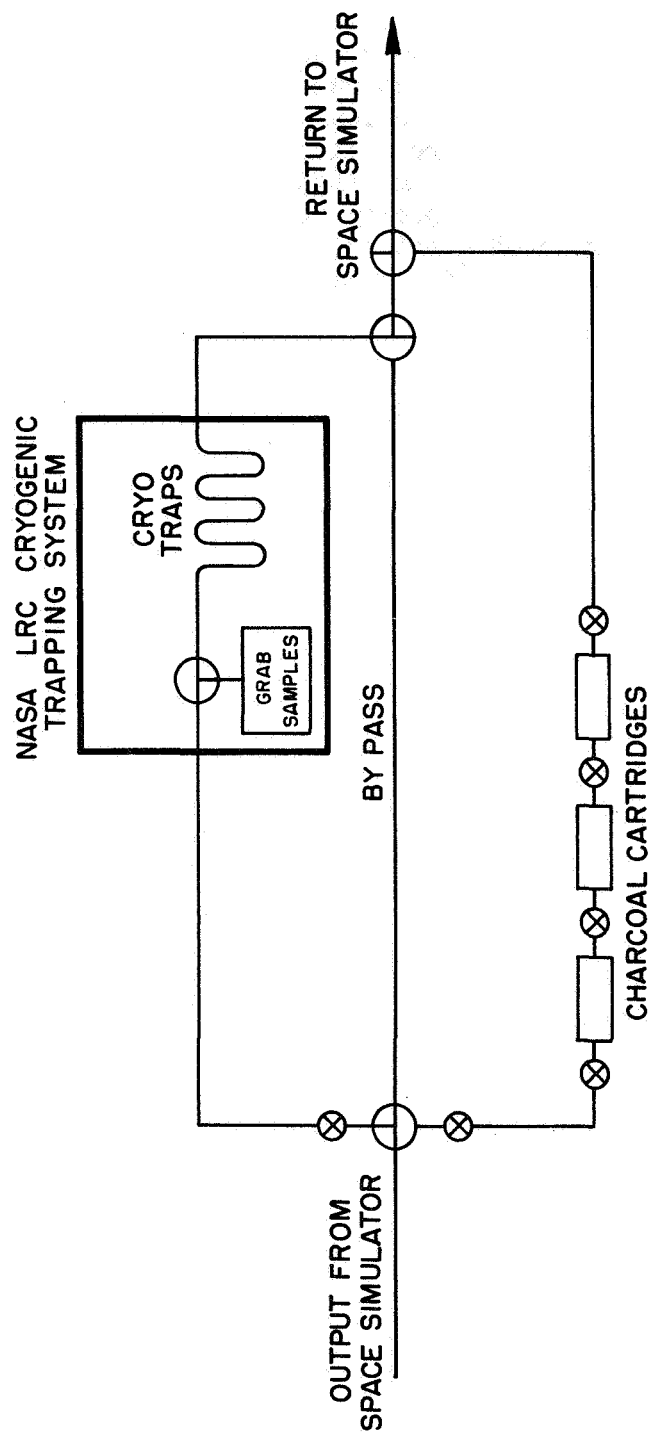
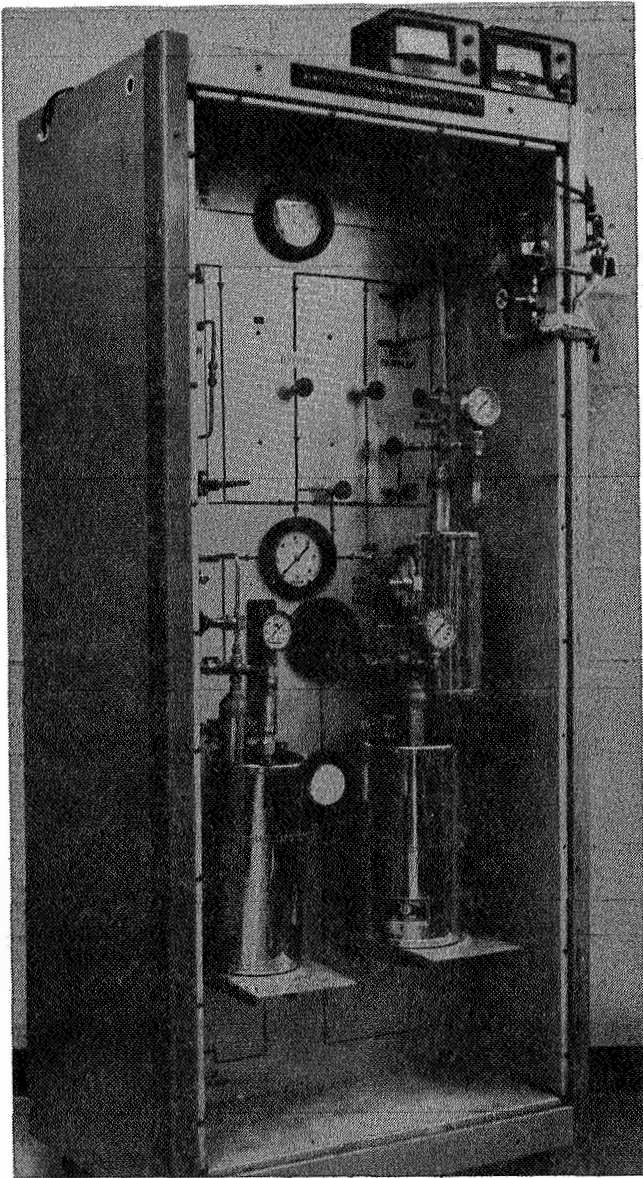
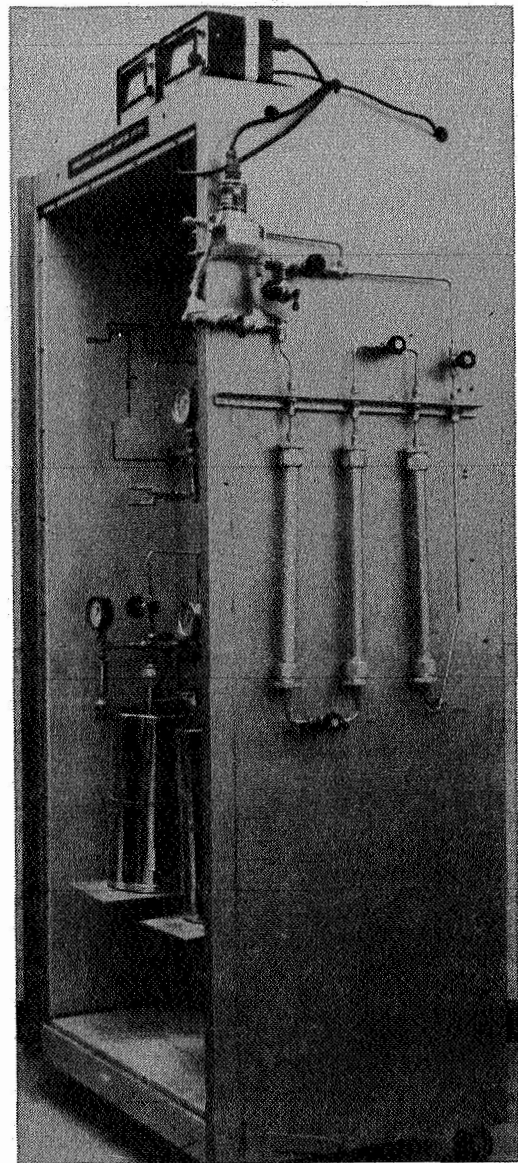


Figure 1.- Gas sampling system.



(a) Front view.



(b) Side view.

Figure 2.- NASA sample acquisition system.

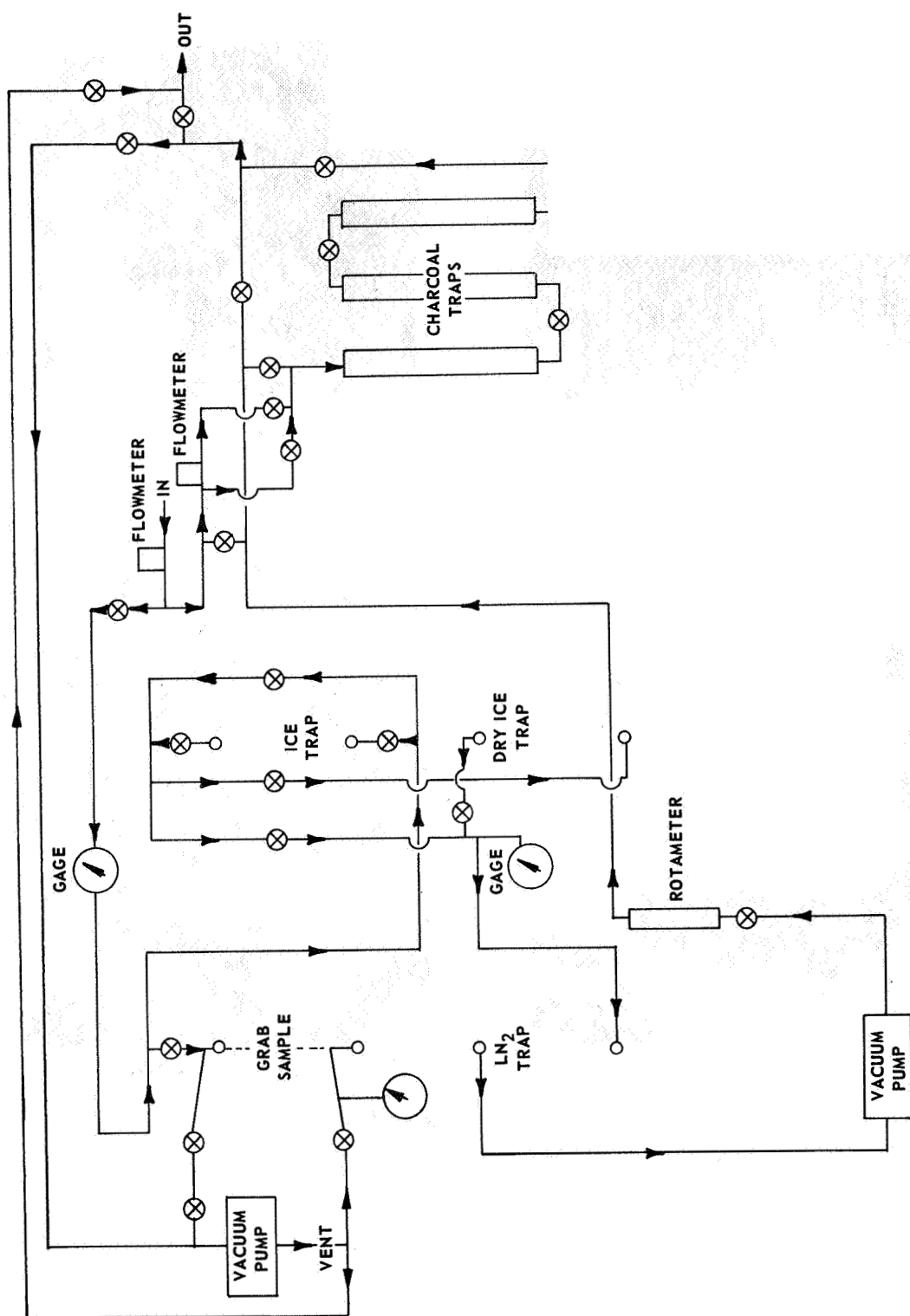


Figure 3.- Atmospheric contaminant sampling system.

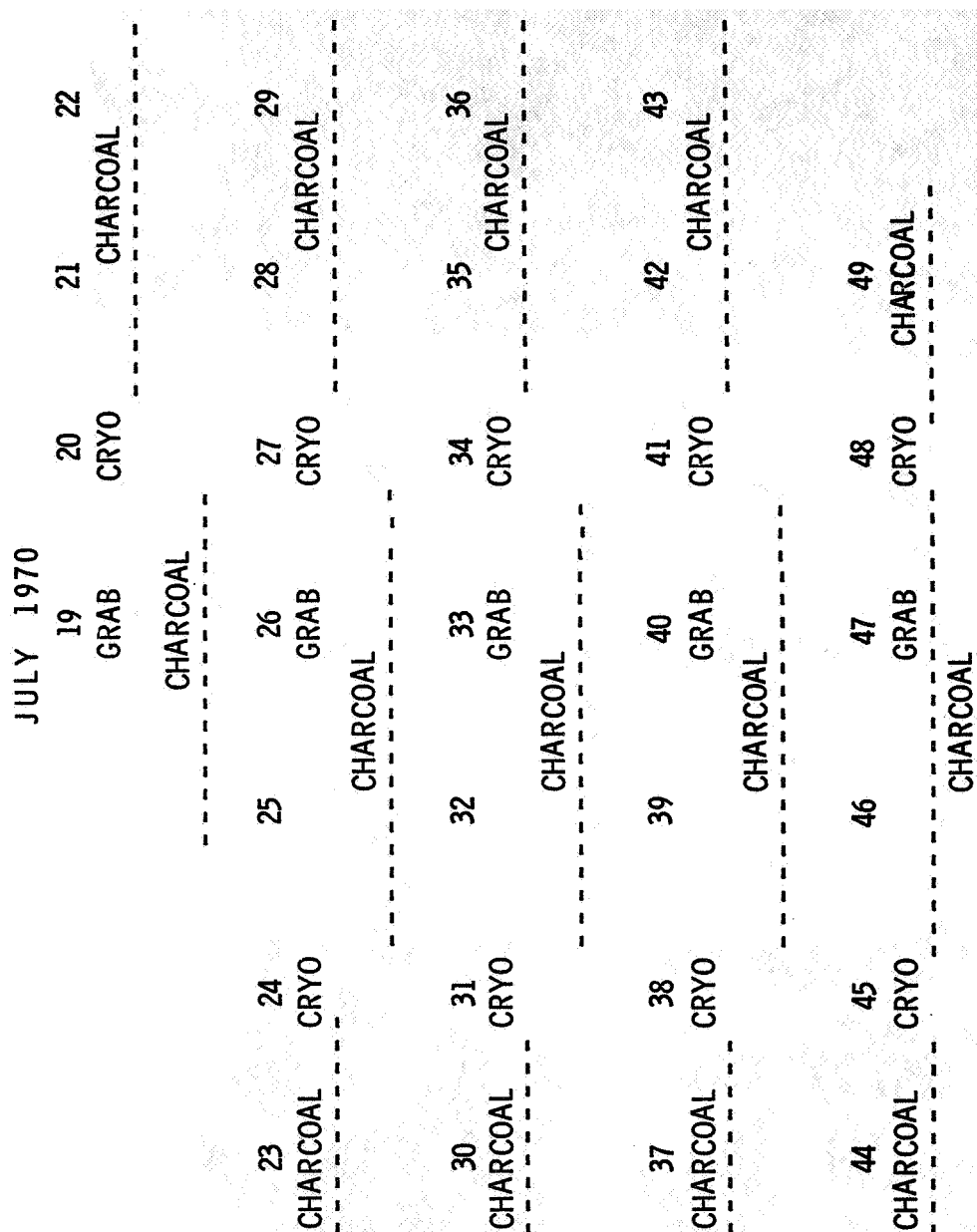


Figure 4.- Typical schedule of sample collection.

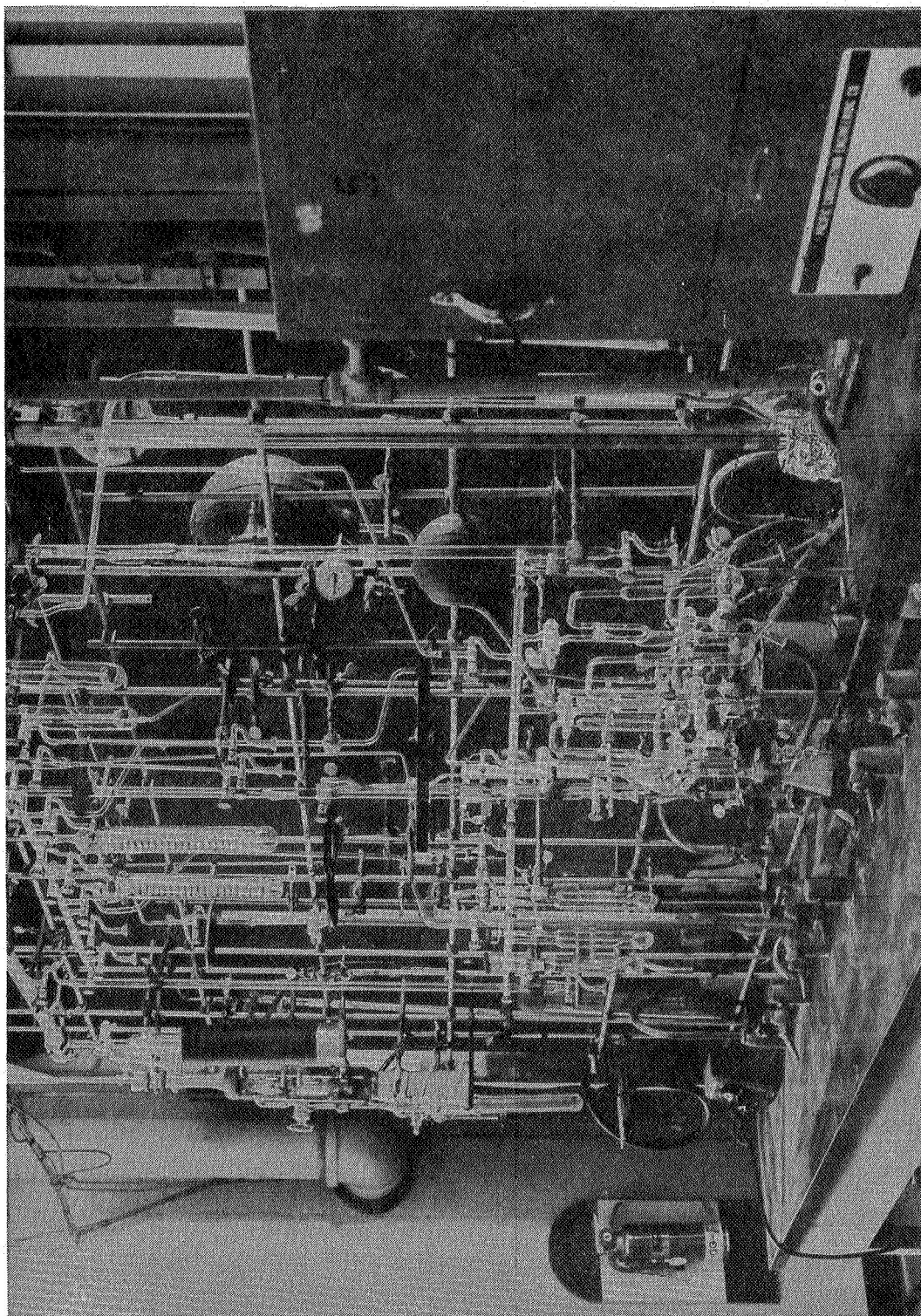


Figure 5.- Vacuum rack used in trace gas manipulation.

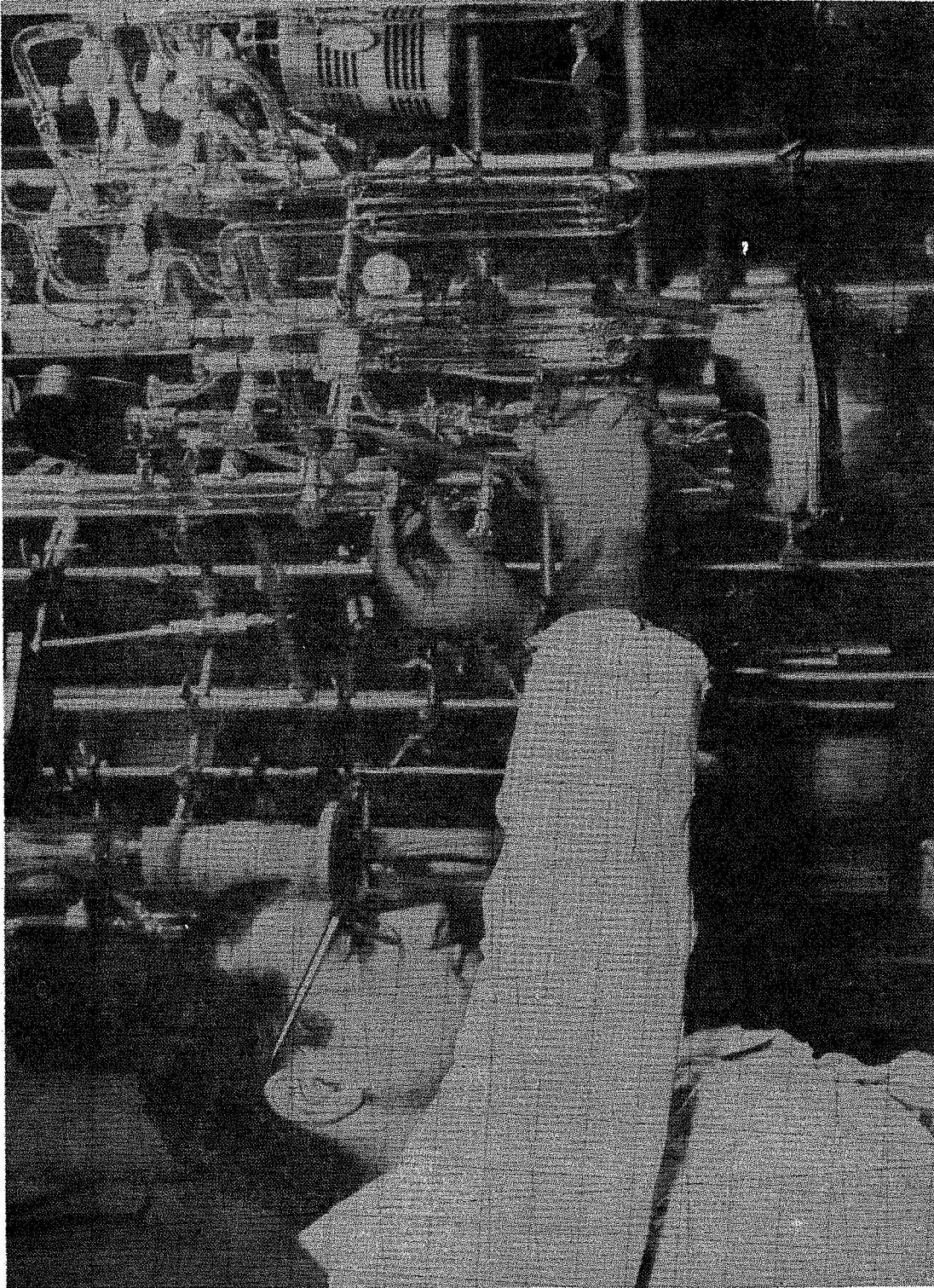


Figure 6.- Thermal-vacuum desorption of charcoal.

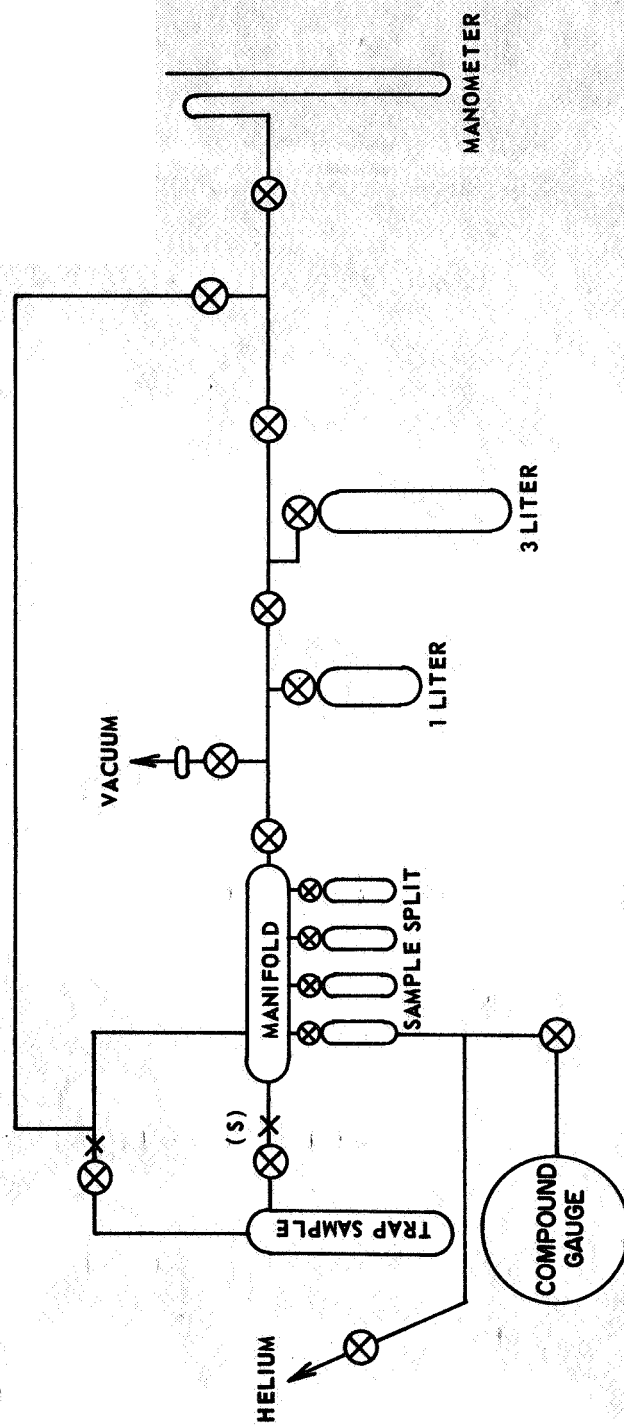


Figure 7.- Sample splitting for grab and cryogenically collected samples.

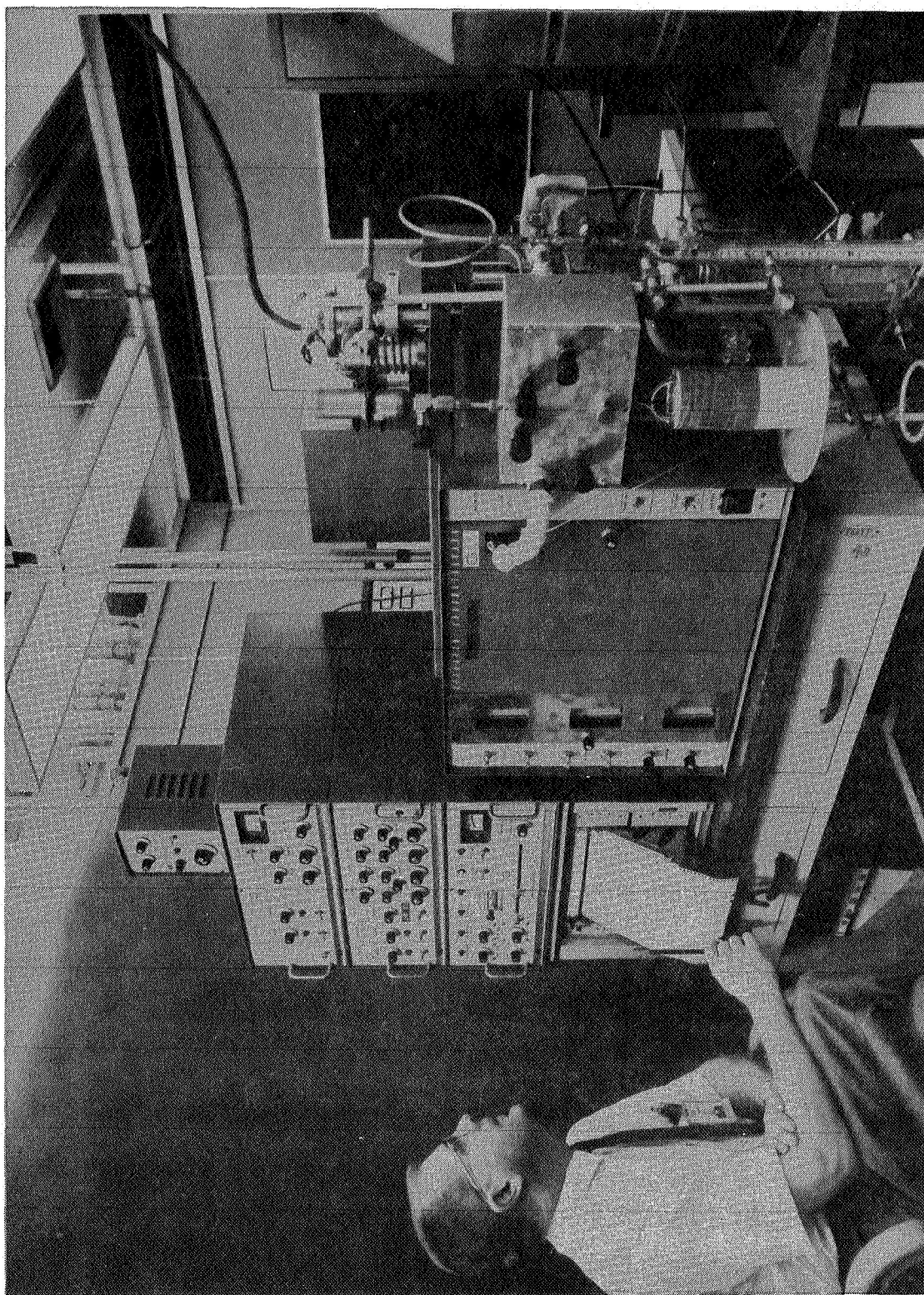


Figure 8.- Gas chromatographic instrumentation.

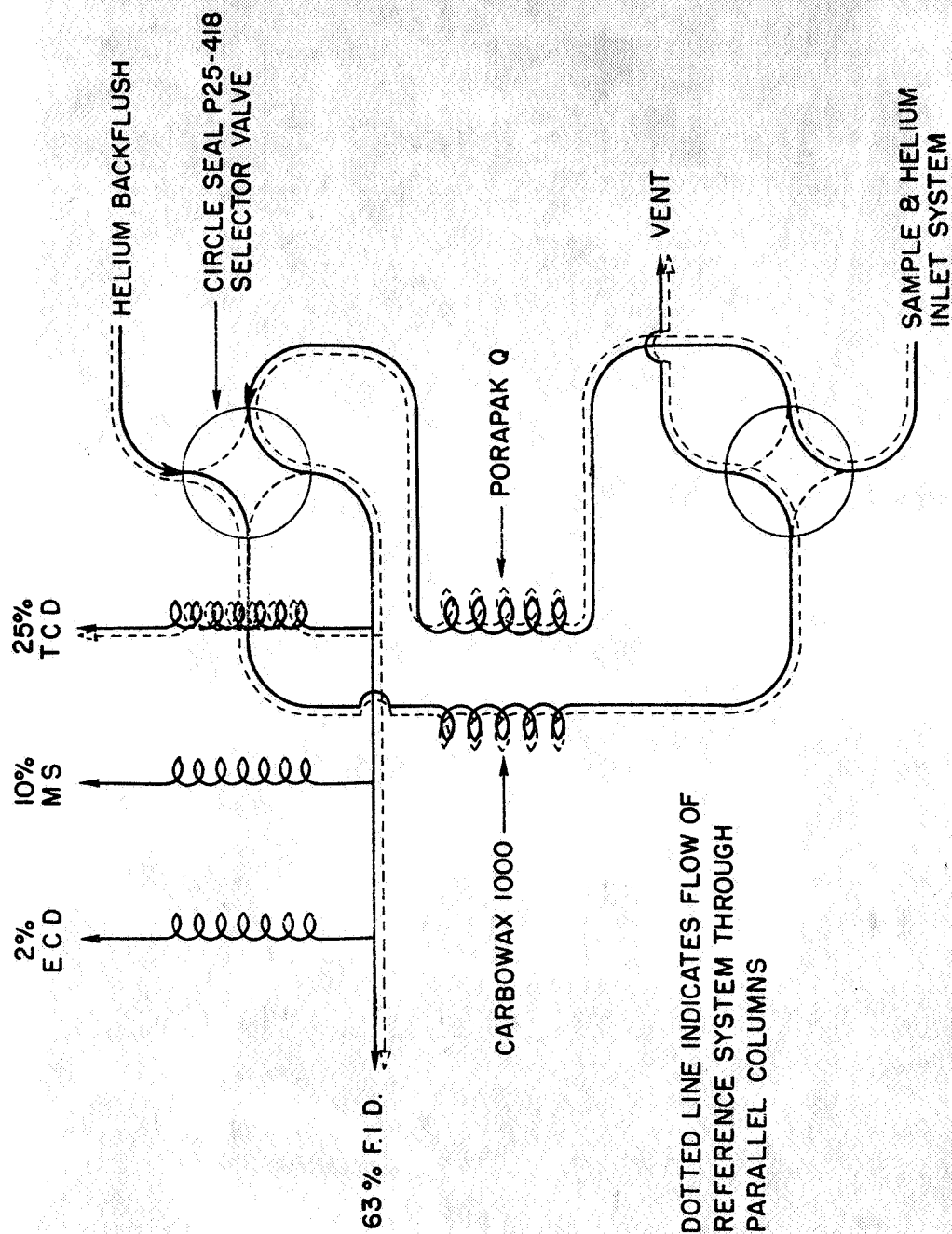


Figure 9.- Gas chromatographic column arrangement.

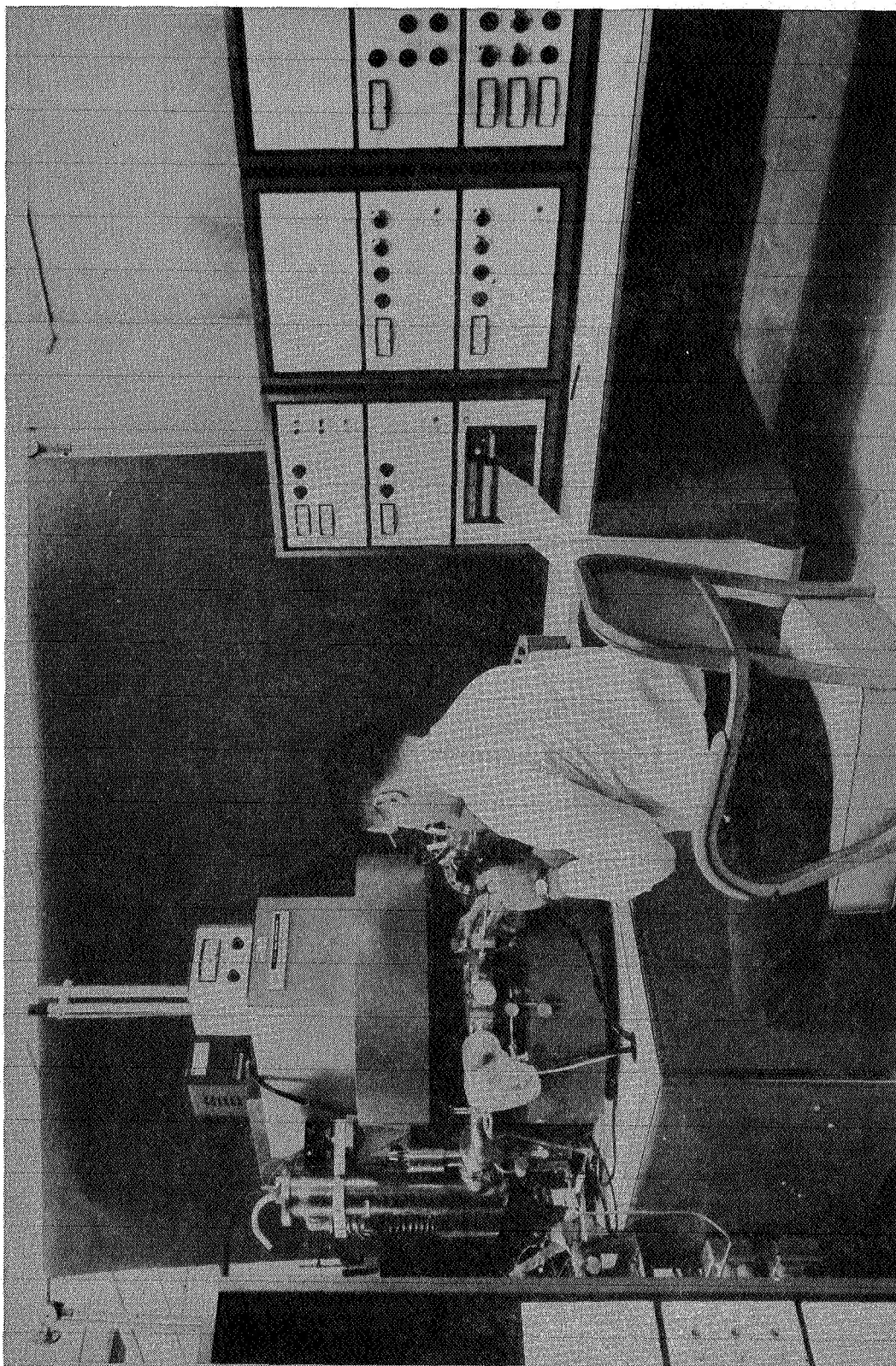


Figure 10.- Mass spectrometer instrumentation.

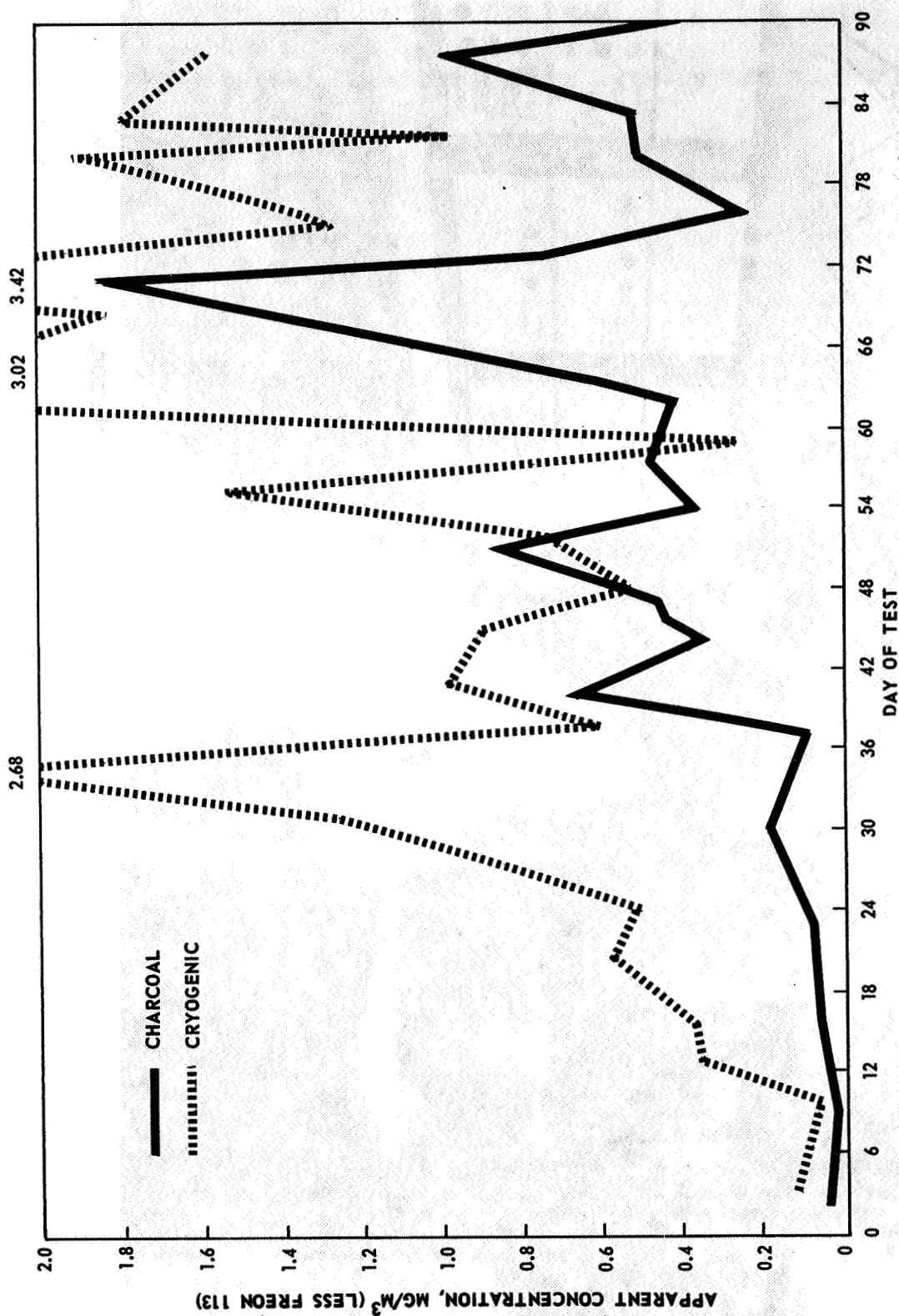


Figure 11.- Sample recovery using two collection methods.

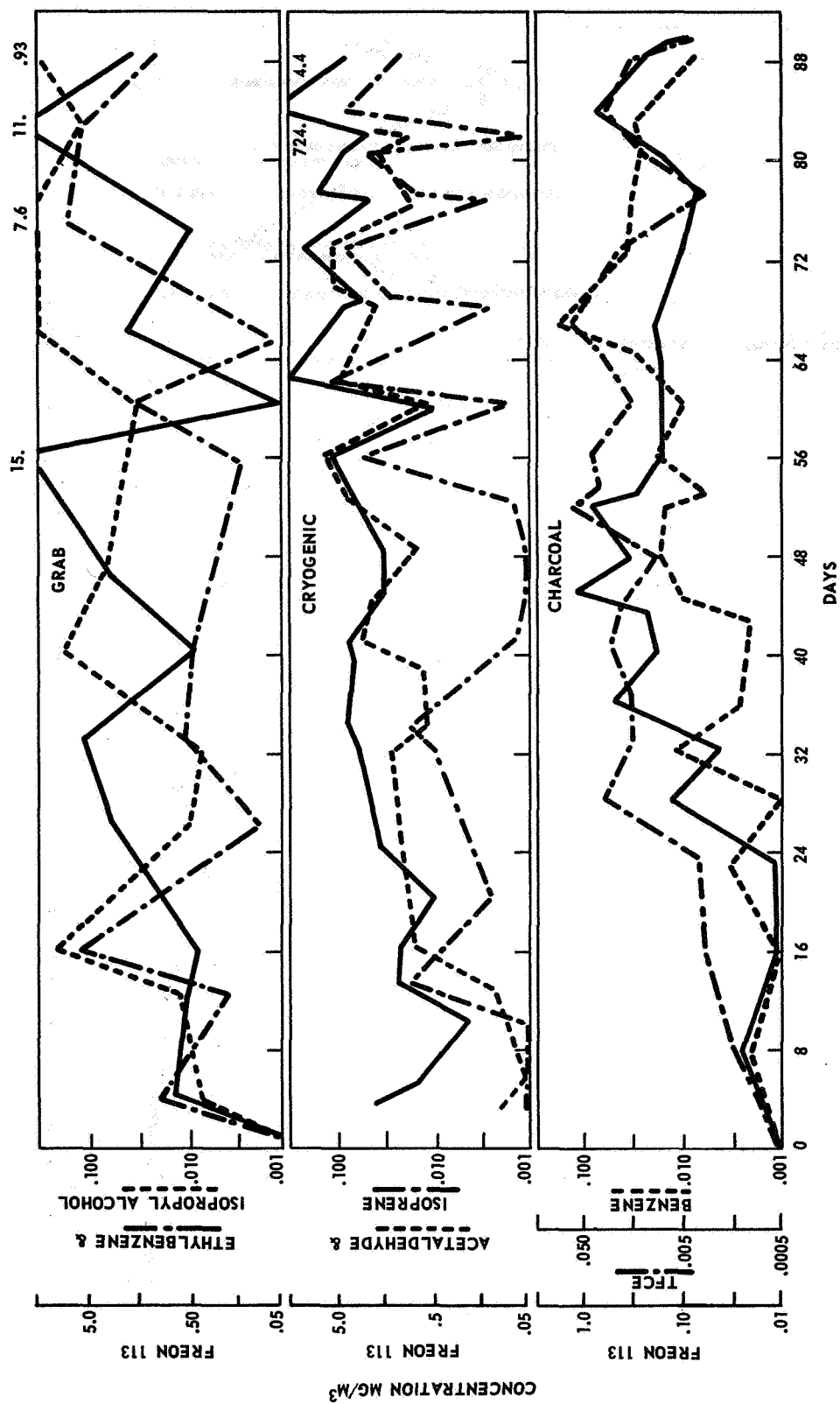


Figure 12.- Concentration change of selected components.

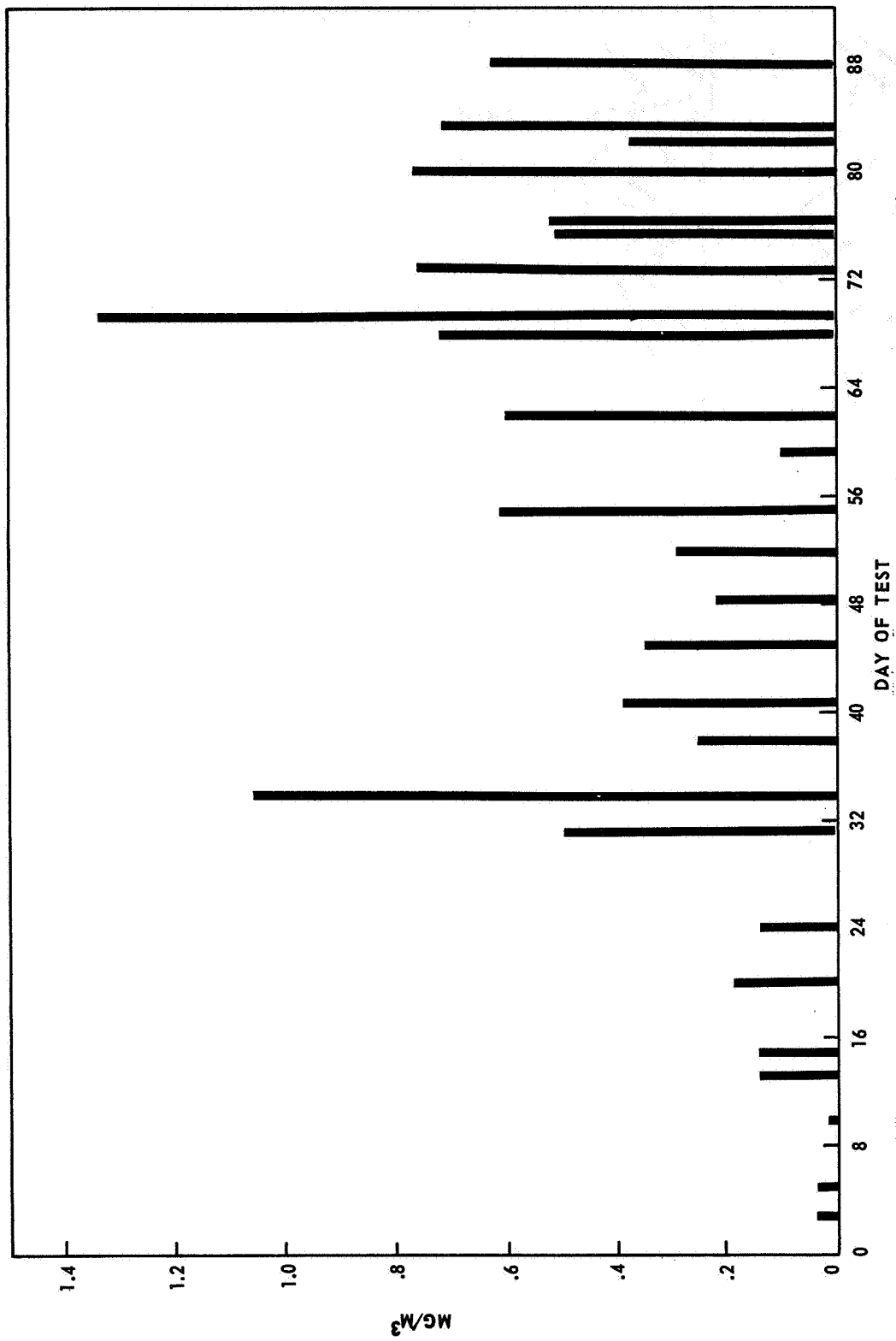


Figure 13.- Total weight of recovered material (excluding Freon 113) using cryogenic collection.

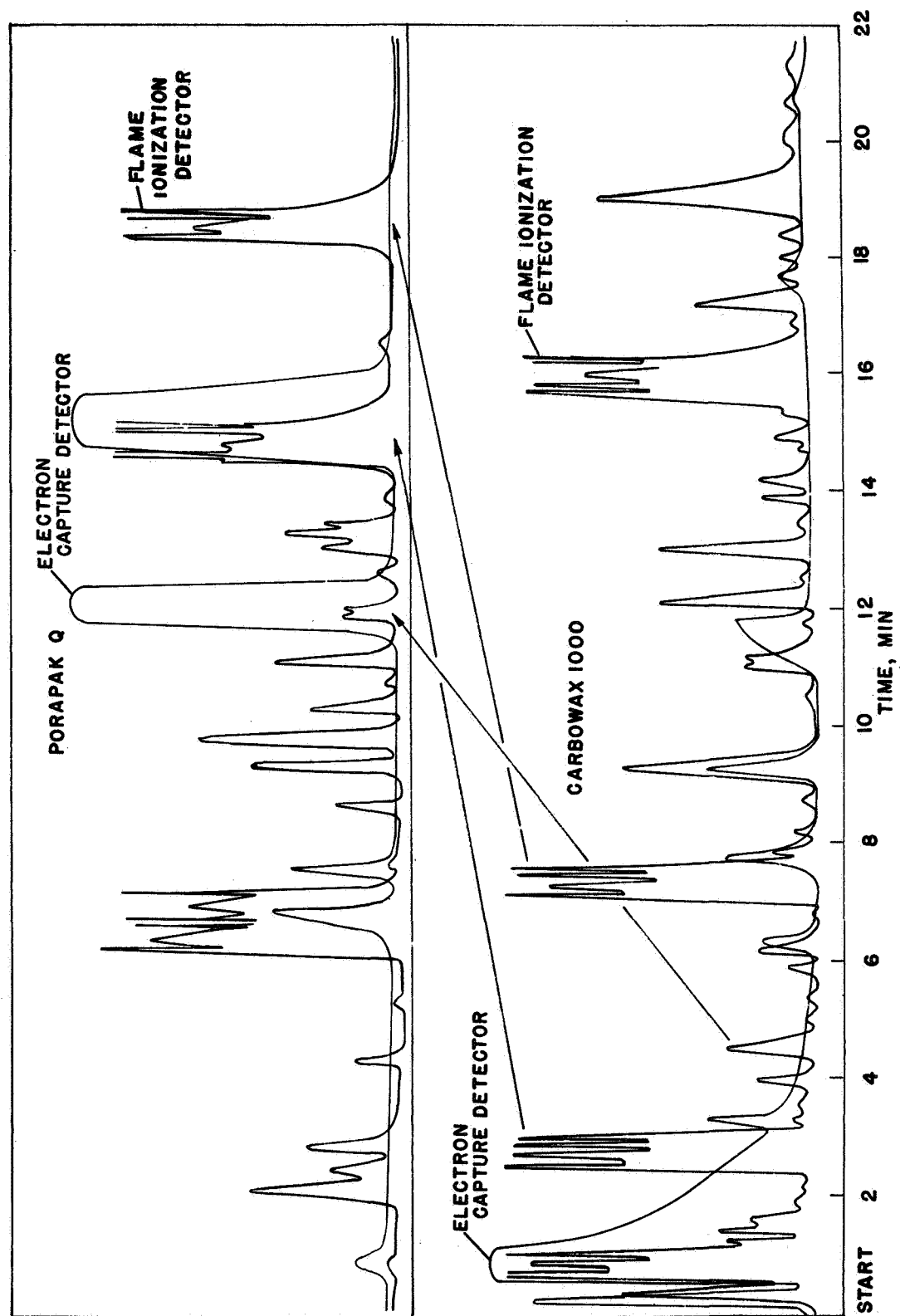


Figure 14.- Selected chromatogram of trace contaminants.

RESULTS OF THE AEROSOL ANALYSIS EXPERIMENT PERFORMED
DURING A 90-DAY MANNED TEST OF AN ADVANCED
REGENERATIVE LIFE SUPPORT SYSTEM

By Walter F. Harriott and Robert A. Walter
DOT Transportation Systems Center

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SUMMARY

Preliminary results from the aerosol analysis experiment are presented. The membrane filter data indicate the trend of particulate concentration in the simulator. The filters have also been partially analyzed by scanning electron microscopy for particle type. Close correlation in particle production has been found between submicrometer and micrometer particles and the particle producing activities within the simulator.

INTRODUCTION

The objectives of the aerosol analysis experiment were three-fold:

(1) The primary purpose was to measure particulate concentrations and size in the simulator during the 90-day test of a regenerative life support system and to evaluate particulate removal by the environmental control system (ECS) and the generation of particulate matter by housekeeping practices, experiments, and equipment.

(2) Provide baseline data in support of Skylab Experiment T-003, In-Flight Aerosol Analysis, which is to be flown to assess the spacecraft particulates generated in the Orbiting Workshop.

(3) Evaluate the condensation nuclei counting technique as a means of detecting submicron particles from overheated materials and their applicability as a warning of prefire conditions in spacecraft. The simulator provided an environment similar to a spacecraft, which could be used for determining the interfering activities that would give rise to false alarm signals and for establishing a baseline background count.

To achieve all the goals of the experiment, analysis of data is being made to determine the levels of particles and their variation with time within the

closed simulator environment; to determine the gross physical and chemical characteristics of the aerosols; to determine the extent of correlation among measurements taken by different techniques at different locations; to determine the extent of correlation of particle concentrations, variations, and characteristics with operating conditions and activities in the simulator; to evaluate activities and operating conditions as to their production of particulate matter; and to provide baseline information for modification and improvement of current sampling techniques.

PROCEDURE

Three measurement techniques for particulates were employed for the experiment.

Filter Air Samplers

Membrane filters with a pore size of 0.8 μm and preloaded into plastic holders were used at locations 1 through 4 (fig. 1). An airflow of 5 liters/minute was maintained by a pump inside the simulator. The filters at locations 1 and 2, food preparation and waste management, were changed daily; locations 3 and 4, air return and air supply, were changed weekly.

Light Scattering Equipment

Four inlet lines terminating adjacent to the membrane filters were sampled sequentially at approximately one hour intervals throughout the 90 days, with the particulates being drawn in at 17 l/min airflow through a light scattering particle monitor (Royco Model 245) located outside the simulator chamber. The count and sizing information for particles from 0.5 to 10 μm was obtained by sorting the pulsed output of the light scattering instrument into 512 channels of a multi-channel pulse height analyzer (Nuclear Data Model 3300) and the results stored on computer compatible magnetic tape (Datamec Model 2020). In addition, the analog output of the light scattering instrument was recorded on a strip chart recorder (Royco Model 503) for the integrated particle count of 0.5 to 10 micrometers.

Condensation Nuclei Counter

A condensation nuclei counter (General Electric Model PCNC-1) was located at station 3, the air return. This instrument gives a gross count of particles from 0.001 to 0.1 μm by light extinction measurement. The instrument was modified for use at 10 psi and 110 V AC power and had a large water reservoir added for reduced maintenance. The condensation nuclei counter operated continuously for the whole test, with the counts recorded on an external analog strip chart recorder.

RESULTS

The particles collected on the membrane filters were counted and sized by optical microscopy in three ranges: less than 2 μm , 2 - 5 μm and greater than 5 μm . Fig. 2 shows the results in the three size ranges for the food preparation area, station 1.

Peaks and trends observed in the food preparation area, station 1, were found in the waste management areas. Weekly trends reflected in the air supply and return filter samples correspond to the weekly averages of the food preparation and waste management areas.

All three size ranges show similar peaks and after an initial cleanup of the simulator a buildup of particles continues through day 50. From day 50 on the trend is downward for the particle counts which can be attributed to more routine operations by the crew, and buildup of a filter cake on the ECS filters resulting in more efficient filtering.

The high counts around day 28 are the result of radioactive source change and maintenance on the vacuum distillation - vapor filtration unit. Microscopic examination indicates that the particulates consist mostly of clothing particulates from the high workload to accomplish the changeover with some contribution from filter material removed from the unit. Other peaks are from days of increased general activity by the crew.

The filters were also examined by scanning electron microscopy for evaluation of particle morphology. Typical results are shown in fig. 3 with tentative identifications of the observed materials.

Figure 4 shows a 12 hour readout of the light scattering instrument and condensation nuclei counter. The agreement between the two curves is quite good and this was typical over the full 90 days of the test.

Both the condensation nuclei counter and the light scattering instrument peaks were correlatable throughout the simulator test period to waste management, food preparation and eating, various exercises, body hygiene and laundry and biomedical checking devices such as the Langley psychomotor test and human describing function.

In active periods, the light scattering instrument recorded up to 30 peaks in an eight hour period; and superimposed on activity peaks, simulator cyclic events were noted at eight different intervals during the 90 days. These events had frequencies of 1 per 15 min, 1 per 26 min, and 1 per 45 min with characteristic peak shapes. Fig. 5 shows a day when the 45 min peak dominated in particle production.

A check of engineering data shows that there is an automatic cycling of filter beds in the molecular sieve on the CO₂ concentrator every 45 minutes.

A condensation nuclei counter could be used as an incipient fire detector in spacecraft if the normal activities did not give rise to an excessive false alarm rate and this test served to establish the condensation nuclei production from common activities. With an anticipated 10,000 particle/cm³ prefire detection threshold level in a spacecraft of Skylab size, the 90-day test indicated satisfactory performance. On very few occasions, vacuum distillation - vapor filtration maintenance and alpha filter changes, the level rose to higher than 10,000, whereas a frozen pump motor indicated clearly an overheated condition.

FUTURE STUDIES

Work is continuing on examining the filters by scanning electron microscopy. In addition, an electron probe will be used for elemental analysis of the particulates of interest. Particles from samples of the common materials in use in the simulator such as clothing, bedding, curtains and soap are being compared to those observed on the filters. The filters from the environmental control system have been obtained from McDonnell Douglas and the filter cake is being examined chemically to determine its composition.

The tape readouts from the light scattering unit contain the particle size distributions and these are being analyzed for comparison of distributions to the producing activity.

ACKNOWLEDGEMENTS

This experiment was supported by the Biotechnology and Human Research Division of OART, Walton Jones, M. D., Director, and the NASA Spacecraft Fire Hazards Steering Committee, I. Irving Pinkel, Chairman.

Drs. Parker Reist and Christopher Martin of the Harvard School of Public Health substantially contributed to the experiment definition and preparation of the filter experiment.

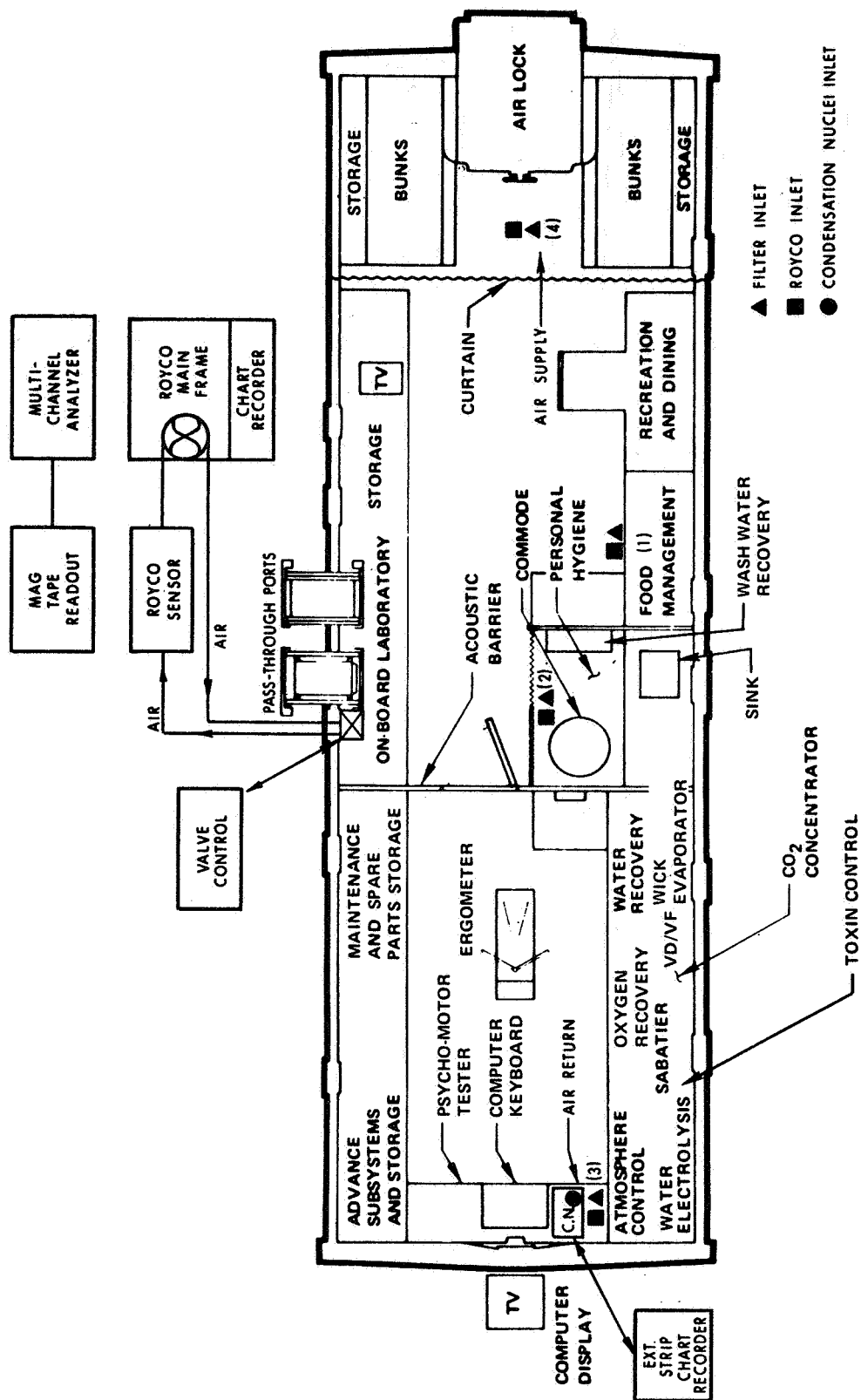
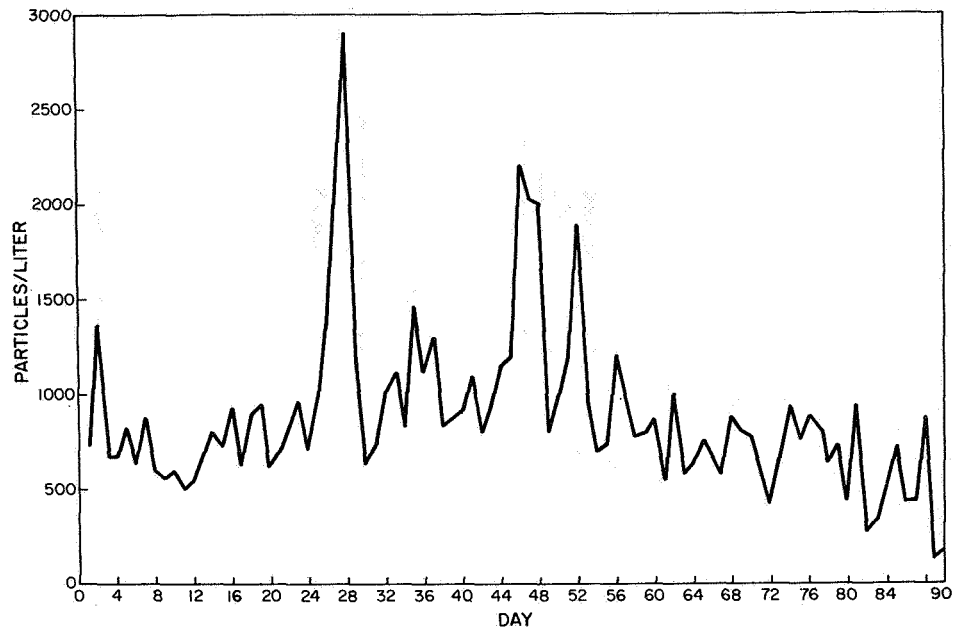
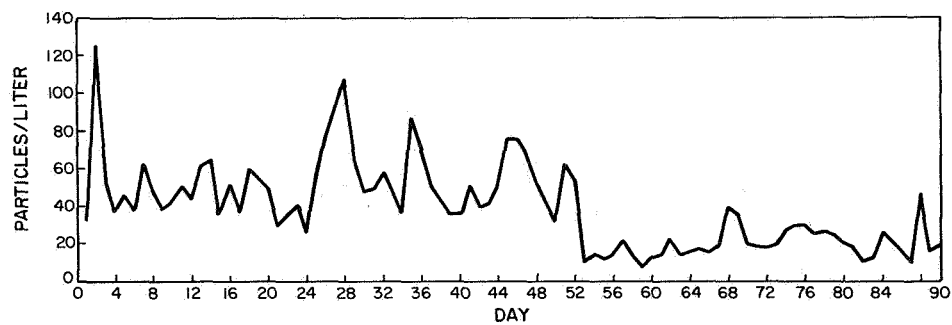


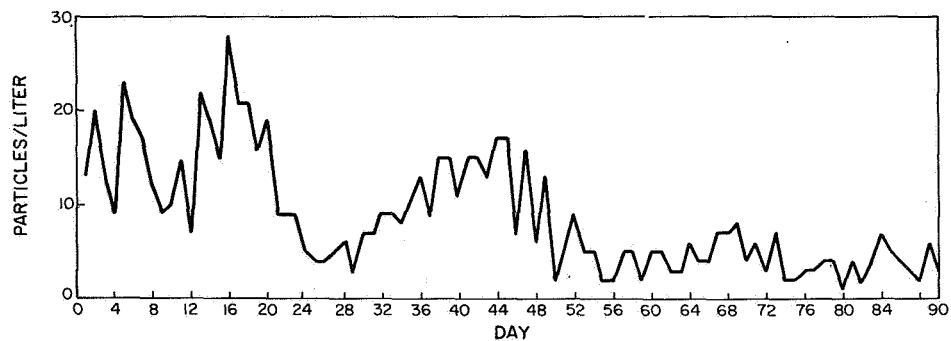
Figure 1.- Aerosol analysis experiment for 90-day test.



(a) Particle size $< 2 \mu\text{m}$.

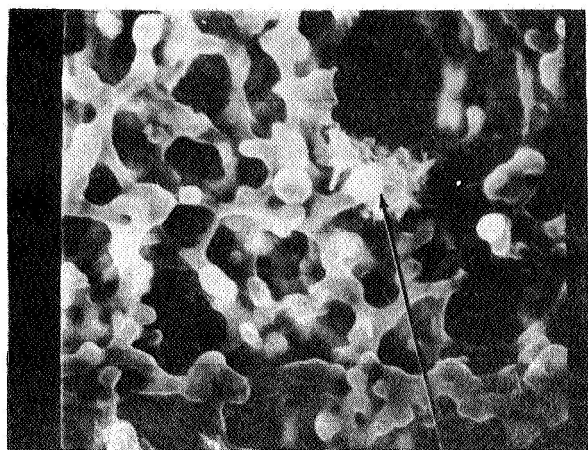


(b) Particle size from 2 to 5 μm .



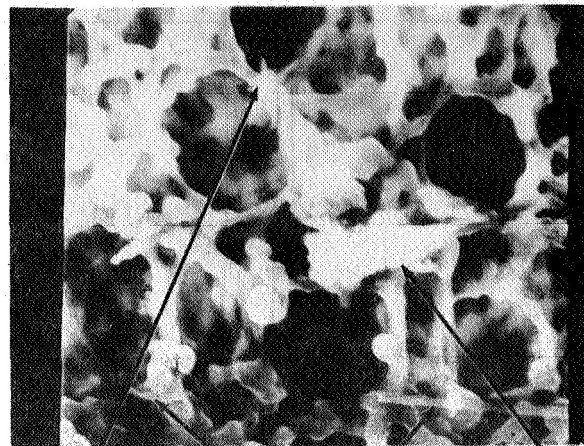
(c) Particle size $> 5 \mu\text{m}$.

Figure 2.- Filter results for food preparation area,
station 1.



(A)

UNKNOWN

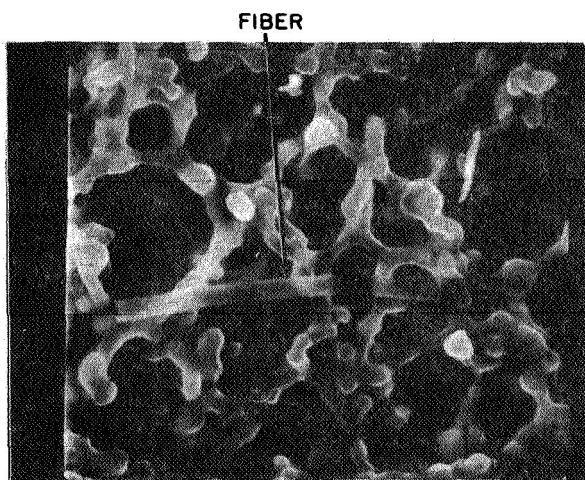


(B)

UNKNOWN

FIBERS

SKIN
FLAKE



(C)

FIBER

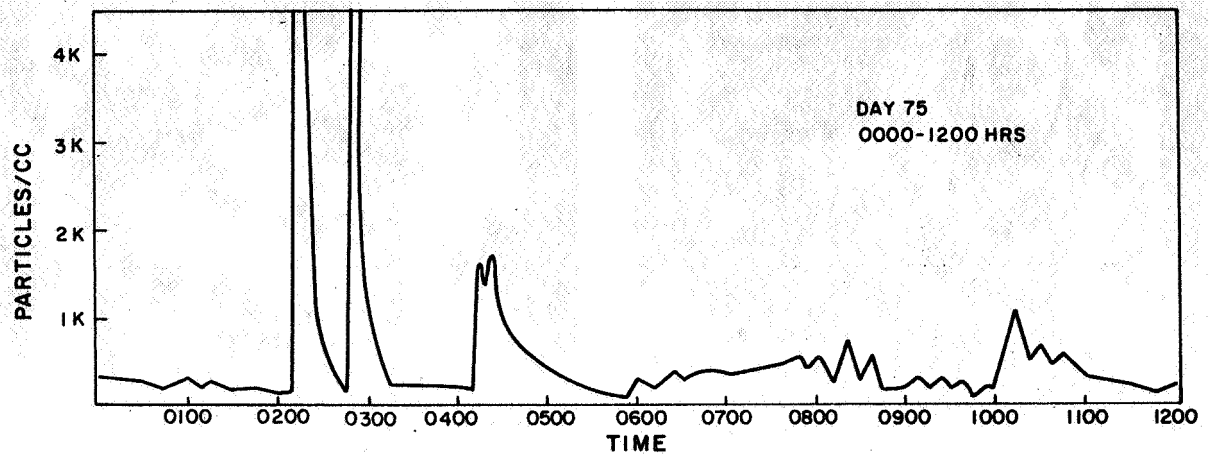


(D)

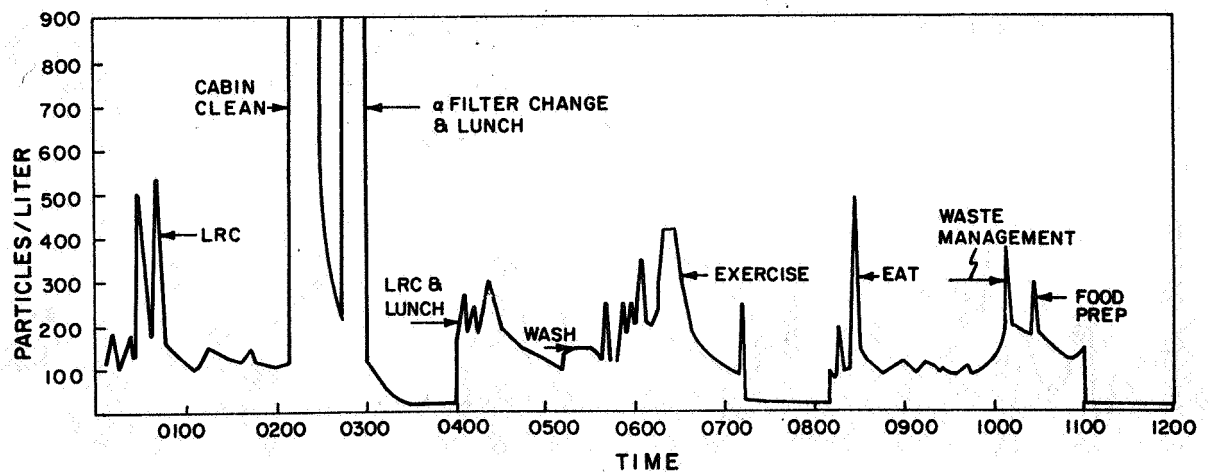
CRYSTALLINE
MATERIAL

UNKNOWN

Figure 3.- Scanning electron photomicrographs of filters for day 28.



(a) Condensation nuclei counter ($0.001\ \mu\text{m}$ to $0.1\ \mu\text{m}$).



(b) Light scattering instrument ($0.5\ \mu\text{m}$ to $10\ \mu\text{m}$).

Figure 4.- Records of 12-hour readout.

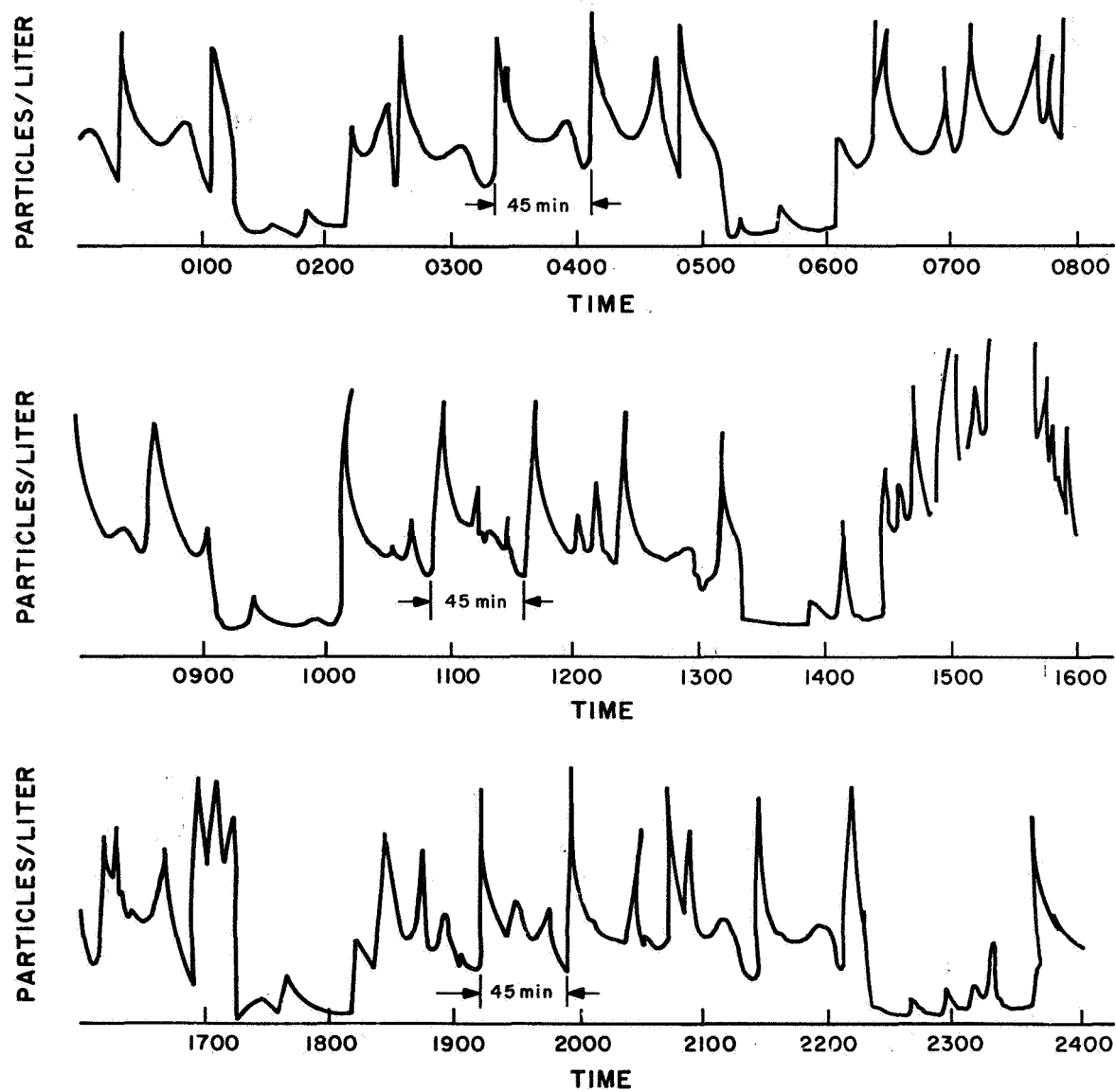


Figure 5.- Light scattering readout ($0.5\ \mu\text{m}$ to $10\ \mu\text{m}$). Cyclic events on day 83.

WATER ELECTROLYSIS SYSTEMS

By E. S. Mills

McDonnell Douglas Astronautics Company

SUMMARY

Three different water electrolysis units were used during the 90-day test of a regenerative life support system. A commercial unit was used for backup to two experimental units. One experimental unit uses a vapor feed and intermittent circulation of electrolyte and was installed inside the Space Station Simulator (SSS). The other unit uses a liquid feed with continuous electrolyte circulation and was installed outside the chamber. All three units operated with some degree of success during the test period. The experimental units provided 71.6 percent of the total hydrogen required and 68.3 percent of the total oxygen required. All units experienced failures. Some of these failures caused early shutdown due to inaccessibility and lack of proper parts, other failures were repairable because the unit was outside the chamber. This program indicated that additional testing of water electrolysis systems is needed. Greater care in hardware selection should be made, and electrolytic cells should be designed to operate with greater gas-to-liquid pressure differentials. Improvements in the performance of two-phase separators are also required.

INTRODUCTION

The gas generation systems for the 90-day manned SSS test consisted of three different water electrolysis subsystems and a stored gas supply. These subsystems were required to produce high-purity oxygen for meeting metabolic and leakage requirements and high-purity hydrogen for carbon dioxide reduction in the Sabatier reactor. The stored gas supply was used only in emergencies where excessive demand exceeded the output capability of the operating electrolysis units.

The electrolysis systems used in this test consisted of a commercial unit and two experimental units developed specifically for this test program. The commercial unit was used for backup when neither experimental unit was capable of meeting either hydrogen or oxygen demands of the simulator cabin. This unit was identified as the Stuart unit and was manufactured by the Electrolyzer Corporation, Ltd. of Toronto, Canada. The other two units were manufactured by Allis-Chalmers Manufacturing Company (A-C) and the Lockheed Missiles and Space Company (LMSC). The Allis-Chalmers unit uses a vapor feed and intermittent circulation of electrolyte and was installed inside the chamber during the test. The Lockheed unit uses a liquid supply with continuous electrolyte circulation and was installed outside the simulation chamber

during the test. All of these systems were used with some success during the 90-day test. All three systems were designed to provide the oxygen requirements of the four-man crew and all three systems experienced some problems.

The following paragraphs briefly describe the salient features of the two experimental systems and the integration of the three systems into the chamber design. Also described are the performances of the two experimental systems as well as the major problems encountered.

SYSTEM DESCRIPTIONS

Allis-Chalmers Water Electrolysis System

The Allis-Chalmers water electrolysis system was designed to be an integral part of the MDAC-West Space Station Simulator. At its present stage of development, it is a nonflight system which incorporates the basic principles and fundamentals of a zero-g flight-type system, but not necessarily the weight, bulk, and detail design. Oxygen output capacity of the system is up to 10 lb/day. To meet the specified requirements of 8 lb/day of oxygen, the system must produce 0.333 lb/hour (0.111 lb/hour/module). This, in turn, requires 0.375 lb of water be fed to the system each hour and 33.9-amp total (an average of 11.3 amps applied to each module). The unit is contained in an enclosure approximately 24 in. wide, 24 in. high, and 18 in. deep, weighing approximately 220 lb fully charged with coolant and electrolyte.

A schematic of the system is shown in figure 1. During normal operation, feed water is pumped to the accumulator from a supply source every 2 hours. The water is then fed on a pressure-demand principle through the separator to the electrolyte cavities in the three electrolysis modules. The water is electrolyzed into hydrogen and oxygen. The O_2 and H_2 are supplied to the SSS accumulators through a condenser and their respective back-pressure regulators. Water vapor, condensed from the O_2 and H_2 gas, is fed back to the electrolysis modules. Every 2 hours the electrolyte solution (35 percent KOH, 65 percent H_2O by weight) in the modules and feed lines is circulated by a pump through the two-phase gas separator to remove noncondensable gases in the system. This purge process lasts approximately 3 minutes. Current to the electrolysis modules is regulated by sensing the oxygen accumulator pressure downstream of the unit to adjust the production rate to meet system demands. The operation is completely automatic after startup is achieved.

Instrumentation on the front panel includes switched readout of individual cell voltages, module voltage, module current, system voltage, system current, module temperatures, and system temperatures. Pressure gages are used to indicate the gas and water pressures in the system manifolds before the condensers and at their respective accumulators. Annunciator lights indicate when the main power to individual modules and individual heaters is on. Alarm lights are provided for high and low hydrogen pressure, high and low water pressure, high oxygen pressure, and high cold-plate temperature.

The unit has several safety devices and control circuits to provide the operator with sufficient information to take corrective action. The modules are protected by fast-acting circuit breakers that limit the current to 20 amps. Fuses are provided to protect individual circuits. The method of safety for the remainder of the fault conditions is a complete shutdown and isolation from the external line. The instant power is cut off, gas generation stops; hence, no change in internal pressure should occur after the unit is shut down. Isolation solenoids for retaining internal pressure for short periods of time after power cutoff prevent unbalancing of the hydrogen and oxygen pressure loops. The isolation valves in the inlet water lines to the modules serve two purposes. At shutdown, they isolate the water cavities to prevent flooding into the hydrogen cavities. They also provide a means of allowing all the flow from the circulation pump to be directed through one module during a purging operation by manually closing two of the three solenoids. All safety devices except the temperature switch operate latching-type relays which in turn operate the indicator lamps on the front panel. The lights remain on even though the fault may correct itself before the operator reaches the unit. A reset switch on the front panel energizes the reset coils in the latching relays.

Lockheed Water Electrolysis System

The Lockheed electrolytic oxygen generator is a water electrolysis system which was suitable for integration into and operation with the environmental control life support system of the MDAC-West Space Station Simulator. Oxygen output capacity of the system is 8 to 10 lb/day at a discharge pressure of 21 to 27 psig. The hydrogen discharge pressure is 9 psig. The outside dimensions of the system enclosure are 24 in. wide, 22 in. high, and 31 in. deep. It weighs 285 lb fully charged with coolant and electrolyte.

A schematic of the unit is shown in figure 2. The concepts employed in the system design include the use of dual-matrix, liquid-center electrolysis cells with a circulating 30 percent potassium hydroxide electrolyte. The generating unit consists of four electrolysis modules, each containing 16 cells connected hydraulically in parallel and divided electrically into two 8-cell banks. Cells within each 8-cell electrical bank are connected in series. Peripheral manifolding within the module provides separate paths for electrolyte circulation, oxygen and hydrogen discharge, and nitrogen purge. Differential pressure control is used to maintain gas-liquid phase separation across absorbent matrices contiguous to the electrodes.

Electrolyte is pumped through a closed circulation loop using one of the two in-line magnetic-coupled centrifugal pumps; the second pump is an in-line spare. The electrolyte leaving the pump passes through the tube side of a shell-and-tube heat exchanger. Coolant supplied to the shell side removes waste heat generated in the electrolysis modules. Flow control valves in these lines are used to balance the flowmeters. Valves in the discharge electrolyte lines from the modules are provided so that a disabled module can be isolated from the circulation loop. During normal operation, these discharge valves are fully open.

Downstream of the discharge valves, the electrolyte is manifolded together and enters the electrolyte reservoir for return to the pump. System pressure is applied with a nitrogen pressurization system on the top of the reservoir.

Water feed for the electrolysis process is supplied by direct injection of liquid water into the reservoir. A gear pump used in conjunction with a flow control and solenoid valve provides the proper water pressure and flow rate.

Hydrogen is delivered from the electrolysis modules at approximately 9 psig. Oxygen, discharged from the electrolysis modules at approximately 9 psig, is pumped to 21 to 27 psig using a diaphragm pump. A pressure regulator across the pump maintains the pump suction pressure at 5 psig.

Nitrogen purge is provided to maintain gas-liquid differential pressure during startup and interim shutdown. When this function is activated, either manually or automatically during safety shutdown, inlet and outlet solenoid valves in the hydrogen and oxygen discharge lines open, allowing nitrogen to flow through the oxygen and hydrogen chambers of the electrolysis modules. A micrometer valve is used to adjust the nitrogen flow rate.

The electrolysis unit is designed to operate in an automatic mode during normal operation except during manual startup and shutdown. Automatic controls include electrolyte temperature which is accomplished by using a thermostat in the electrolyte discharge line from the modules. Coolant flow to the electronics cold plate is continuous and is regulated with a flow control valve. Water balance in the circulating electrolyte is maintained relatively constant by controlling electrolyte volume in the reservoir. Two differential pressure controllers mounted on each module are set to control the hydrogen and oxygen pressures at 25-in. water above the electrolyte pressure in order to maintain gas-liquid phase separation. Each electrolysis module is provided with a current-controlled switching regulator to control the dc current input.

Safety circuits are provided to automatically shut down the system under abnormal operating conditions. In an automatic shutdown, electrolysis module power is turned off, the electrolyte pump, water feed system, and system reset are turned off, nitrogen purge to the modules comes on, and the cause of shutdown is indicated on the front panel. The shutdown signal is derived from nongate circuitry which continuously monitors the following safety circuits: (1) module temperatures, (2) O₂ and H₂ safety pressure, (3) H₂ detector, (4) electrolyte volume, and (5) interruption of 60-Hz power. Each safety circuit, except item (5), has its own memory latch which allows the system to remember what type of malfunction caused the shutdown. The input to these memory latches is driven by the safety sensors. When an out-of-tolerance condition exists, the respective latch will be set. A reset condition can be obtained by depressing the system reset button.

SYSTEM INTEGRATION

The Stuart unit used in this test was an upgraded version of the system configuration used in the 60-day test conducted in 1968. Detailed schematics and system descriptions are provided in reference 1. Briefly, the unit consists of an air-cooled transformer and rectifier, five Stuart electrolytic cells connected electrically in series, a water seal, a low-pressure gas holder for each gas, an air-cooled electrically driven compressor for each gas, a purification system for each gas, storage and reserve tanks for each gas, cell interconnecting piping, various protective devices, and automatic controls.

Figure 3 indicates how the three electrolysis systems were integrated to supply hydrogen and oxygen to the other SSS subsystems. The Stuart system had its own gas accumulators. Oxygen from the Stuart unit went directly to the two-gas control unit. Hydrogen from the Stuart unit went through a Deoxo purifier, common to all electrolysis units, before reaching the Sabatier unit. The Allis-Chalmers and Lockheed units were connected in parallel and used common accumulators. Preceding the accumulators were Deoxo purifiers. The piping arrangement provided the capability, on the oxygen side, to fill the internal accumulator from either the Allis-Chalmers unit or the Lockheed unit while the Stuart unit was meeting demands of the two-gas control. The Stuart unit was designed and operated to maintain constant pressure in its own gas accumulators; any excess gas was vented overboard. On the hydrogen side, less versatility existed. The Lockheed unit could operate when either of the other two systems were providing hydrogen to the Sabatier reactor. If the Allis-Chalmers unit was providing hydrogen, the Stuart and Lockheed units were set to vent excess gas. If the Stuart or Lockheed units were operating and providing hydrogen gas to the cabin, the Allis-Chalmers unit had to be inoperative. No major problems were encountered with this lack of versatility; however, any future designs should include the ability to operate any of the systems without interference with any other.

TEST RESULTS

Allis-Chalmers Water Electrolysis System

Analysis of collected data has indicated that the average oxygen requirement is 9.58 lb/day. Figure 4 shows that value as well as the quantity of gas generated by each of the experimental electrolysis systems during the 90-day period. The Allis-Chalmers unit operated satisfactorily during the first few hours without any difficulties, then high module temperatures and cell voltages appeared. The amperage levels were reduced, and the unit seemed to settle down to stable operation, but at reduced capacity. Early on day 3, it was apparent that the module water pressure was very low relative to the oxygen and hydrogen system pressures. The low water-to-oxygen differential pressure switch did not appear to be functioning as the differential exceeded 11 psia and the operating manual indicated automatic unit shutdown would ensue if the water pressure was more than 4 psi below the oxygen pressure (ref. 2).

All corrective efforts to raise the module water pressure were unsuccessful. Evidently a blockage existed between the water supply solenoid and the modules. Tests conducted subsequent to the simulator test have not identified this blockage. All through the early part of day 3, cell voltages tended to rise. Module amperage was reduced and the electrolyte was circulated at longer and more frequent intervals. The unit was finally shut down on the morning of test day 3. All modules were flushed for long periods of time on the separate flushing unit to ensure the proper wetness and electrolyte concentration in the matrices.

A number of attempts were made to restart the unit between days 3 and 18. During that period, problems were encountered with the MDAC-installed nitrogen regulator and with electrical shorts in the zener diode and the bias-power relay. After correcting these problems, the unit was restarted on day 18. Again problems of high cell voltage were experienced. Difficulty was also experienced in maintaining the module water pressure at 2 psi or less below the oxygen system pressure. After trying all possible corrective measures without any improvement in performance, the unit was permanently shut down on the evening of the 20th test day. Detailed analysis of test data collected from tests conducted prior to the 90-day test as well as data collected from the 90-day test indicated that some damage may have been done to the modules before the test that had caused an increase in the internal resistance of the modules thus causing increased voltages within each cell. This problem was amplified by the high differential pressure between the module water and hydrogen system. The high differential pressure allowed hydrogen cross-leaks that limited water vapor diffusion to the electrolyte matrix. This caused further concentrating of the electrolyte and still higher voltages due to matrix drying.

During the 98 hours of operation of the Allis-Chalmers unit, it produced 22.4 lb of oxygen and 2.8 lb of hydrogen. This is an average of 57.3 percent of the required oxygen for the 4-day period. This unit provided, during its limited operating life, approximately 2.6 percent of the total oxygen and 2.7 percent of the total hydrogen required by the SSS during the 90-day test. A maintenance summary is shown on table 1.

Lockheed Water Electrolysis System

The Lockheed unit was installed outside of the space simulator (in accordance with refs. 3 and 4) and operated on vent mode during the first 3 days; that is, all oxygen and hydrogen were vented to ambient. On day 3, a nylon fitting in module 1 was found to be leaking hydrogen. The unit was secured and representatives from Lockheed made the necessary repairs. Due to the outside installation and accessibility of the unit, repairs were accomplished and the unit reinstated to normal operation. The reduced performance shown on figure 4 between day 3 and 11 was caused by frequent unexplained shutdown of the 28 vdc power supply and a loose hydrogen fitting.

The next major failure was identification of nitrogen in the hydrogen and oxygen supplies. Two solenoid valves were found to have lost their seals and were allowing purge nitrogen to leak into the oxygen and hydrogen gas passages. A long shutdown was required because replacement parts had to be obtained

from the manufacturer. After repairs to the solenoid valves, the unit was restarted but capacity was reduced because of intermittent automatic shutdown by module 2 overtemperature protection switch. This was disconnected and the unit seemed to perform trouble-free until day 40. Early on the morning of test day 40 the facility power was lost. During restart of the Lockheed unit, smoke was detected from module 1. This was caused by an electrical short from moist potassium carbonate collecting across electrodes of different cells. The carbonate collected from a leaking fitting above the module. The problem was overcome by using installed redundancy (module 4). Module 1 was isolated and the leak repaired.

The major shutdown on day 45 was caused by hydrogen leaks in the bottom of the modules 2 and 3. Module 1 was disassembled and new matrices were installed, also new temperature switches were installed. New fittings were installed in the bottom of modules 2 and 3. Good operation was experienced until days 58 to 60 when the cooling unit, supplying chilled water to the electrolysis unit, developed a clogged filter and cooling capacity was reduced. A nitrogen supply solenoid valve also stuck and required cleaning. Also during this interval, the 28-vdc logic power supply failed. After the necessary repairs, the unit was restarted and operated at required gas generation rates for 2 days. At this time, cross-leaks were discovered in module 2. The unit was stopped and module 2 was rebuilt with new matrices and the unit was restarted. On day 68, more gas bubbles were observed in the circulating electrolyte of all modules and the hydrogen back pressure was found to be up to 11.3 psig instead of the design value of 9.0 psig. This high back pressure was caused by the high venting rate of hydrogen through a fixed orifice in the hydrogen wet test meter. Returning the hydrogen pressure to the proper value eliminated most of the bubbles in the circulating electrolyte. The unit was observed for the next few days and on day 73 the unit was shut down to allow Lockheed personnel time to rebuild modules 1, 3, and 4. All matrices were replaced in these three modules. The unit was restarted, but module 3 still showed evidence of cross-leaks and it was decided to operate on modules 1, 2, and 4 for the remainder of the test. On day 76, an electrical problem developed in the circuitry of module 1. This was solved by electrically cross-connecting modules 3 and 1. That is, module 3 circuitry operated module 1 electrolysis. The unit operated at just under chamber requirements and without additional failures until the end of the test period. A maintenance summary is shown on table 2. Many of these repairs could not have been accomplished if the unit had been installed inside the SSS because of the unexpected nature of the failures, the special skills required, and the need for safe checkout of performance before gas usage was allowable.

During the 90-day test, this unit operated a total of 1,681.2 hours or 70.1 days. The unit supplied the chamber a total of 62.2 days and for 7.9 days the gas generated by the unit was vented to ambient. It delivered 566.02 lb of oxygen and 55.7 lb of hydrogen to the chamber. This represents 68.9 percent of the hydrogen used by the Sabatier unit and 65.7 percent of the oxygen required for leakage and metabolic consumption. Average oxygen production rate for this unit was 9.1 lb/day.

The Stuart electrolyzer unit provided 23.0 lb (28.4 percent) of the hydrogen to the Sabatier unit and 258.3 lb (30.0 percent) of oxygen to the chamber. Also, 15.3 lb (1.7 percent) of oxygen was provided from high-pressure storage.

CONCLUSIONS

All three water electrolysis systems operated with varying degrees of success during the 90-day test period. The commercial unit experienced the least number of failures as was expected. The experimental units had more failures but still were able to supply 71.6 percent of the required hydrogen and 68.3 percent of the required oxygen. It is evident from the test experience that additional development and testing are required before advanced concepts of water electrolysis systems are ready for space applications. It is also evident from the test program that qualified personnel with the appropriate spare parts can complete very significant repairs. The Allis-Chalmers unit, being installed in the chamber, was not accessible by highly qualified personnel nor were spare parts available. The Lockheed unit, being installed outside the chamber, was accessible for complete rebuilding of modules when required. Should the roles have been reversed, less favorable results would probably have been obtained on the Lockheed unit. Selection of better operating hardware and redesign of modules to withstand greater pressure differentials across the matrices would have reduced the overall maintenance of both units. Improved design and performance of two-phase separators are also required.

REFERENCES

1. 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part I- Engineering Test Results. NASA Report CR 98500, December 1968.
2. Operation and Maintenance Manual for Water Electrolysis System. Allis-Chalmers Advanced Electrochemical Products Division, Greendale, Wisconsin 53129, June 1970.
3. Instruction Manual for Electrolytic Oxygen Generator. Lockheed Missiles and Space Company, Sunnyvale, California, May 1970.
4. Test Plan and Procedure, Operating 90-Day Manned Test of a Regenerative Life Support System. NASA-LRC contract NAS1-8997, DAC 63303, June 1969 with changes through March 1970.

TABLE 1.- ALLIS-CHALMERS UNIT MAINTENANCE SUMMARY

<u>Activity</u>	<u>Spares Usage</u>	<u>No. of Times</u>	<u>Hours Required</u>
Purged modules manually to lower voltage		30	7.5
Flushed modules with service unit		3	6.0
Replaced modules	2 Modules	2	2.0
Replaced diode in control	Zener Diode	2	3.0
Replaced N2 regulator	Pressure Regulator	2	1.0
Cleaned N2 regulator		1	1.0
Replaced plugged oxygen purifier**	Deoxo Unit	1	1.0
Shorted out module cells		2	0.5
Flushed water separator		1	1.0
Jumpered failed relay	Wire & Electrical Terminals	1	2.0
Modified timer to increase automatic purge frequency		1	0.5
Disconnected automatic current control		1	1.0
		<u>47</u>	<u>26.5</u>

** Outside activity

TABLE 2.- LOCKHEED UNIT MAINTENANCE SUMMARY

<u>Activity</u>	<u>Spares Usage</u>	<u>No. of Times</u>	<u>Hours Required</u>
Repaired H ₂ leak in Module No. 1**	Misc. nylon fittings	1	3.0
Repaired H ₂ leak in fittings**		1	1.0
Replaced malfunctioning power supply**	Power supply	1	2.0
Replaced leaking N ₂ solenoid valves**	2 Valves	1	1.5
Disconnected overtemperature switch**		2	0.1
Repaired short in Module No. 1**	4 Epoxy frames & Asbestos Matrix	1	16.0
Repaired H ₂ leak in Modules No. 2 and 3**	Misc. nylon fittings	1	5.0
Replaced overtemp switches**	2 Switches	1	0.8
Repaired N ₂ solenoid valve**		2	2.0
Replaced control and logic power supply**	Electronic Control	1	2.0
Added relay to control circuit**	Relay	1	1.0
Rebuilt Module No. 2**	Asbestos Matrix	1	16.0
Rebuilt Modules No. 1, 3 and 4**	Asbestos Matrix	1	32.0
Switched electronic control on Module No. 1**		1	0.8
		<u>16</u>	<u>83.2</u>

** Outside activity

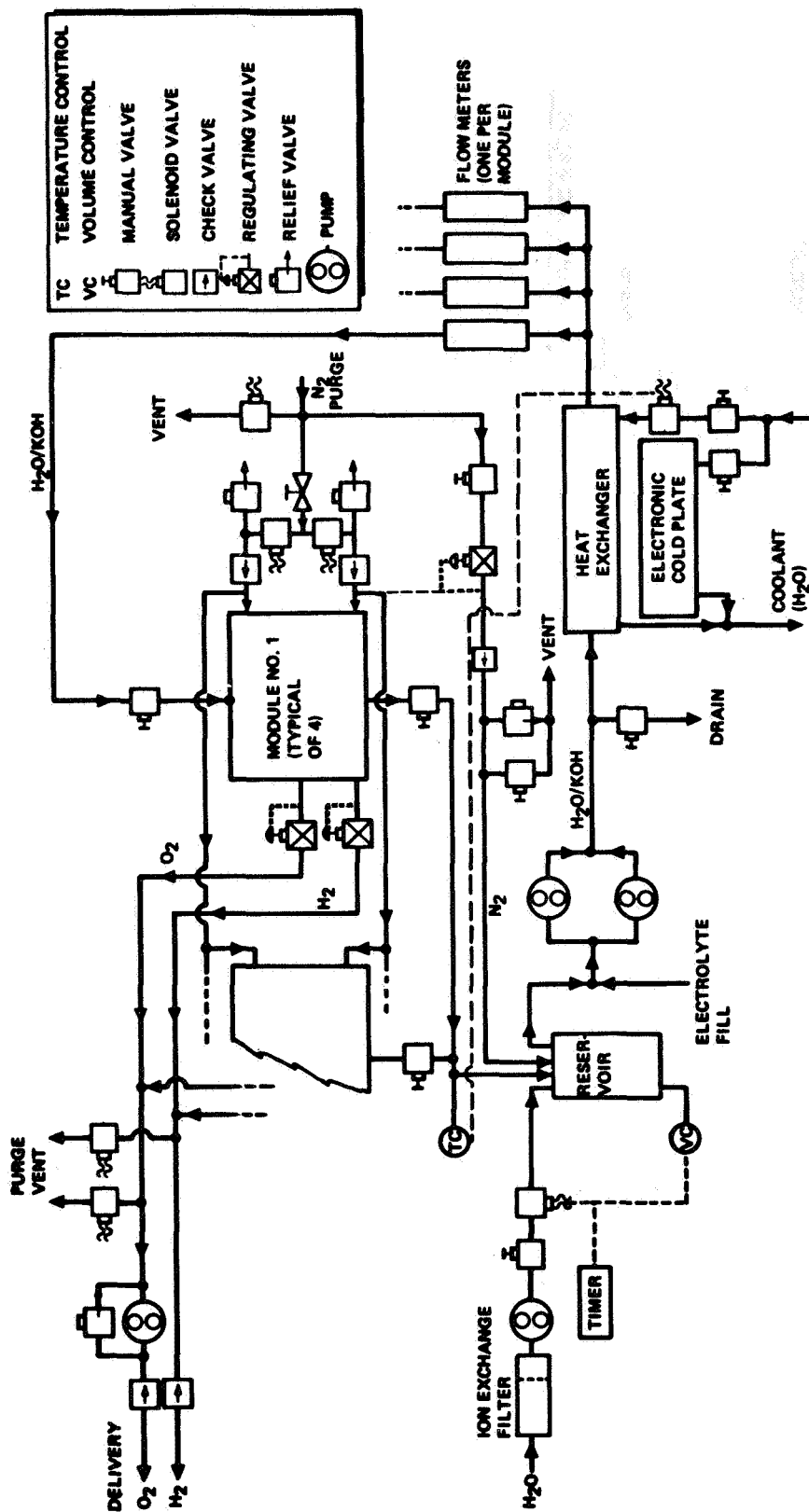


Figure 2. - Lockheed water electrolysis unit.

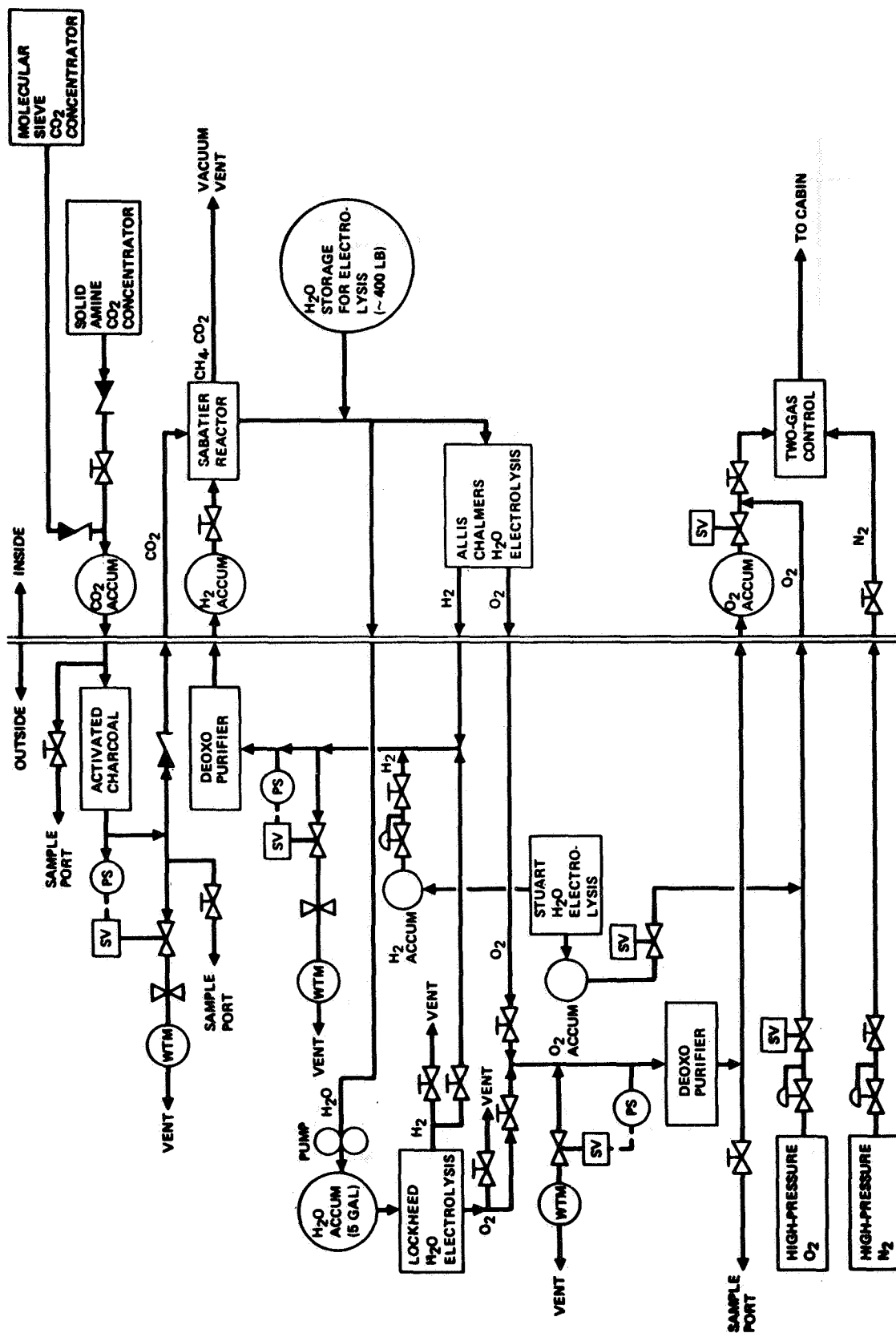


Figure 3.- Simplified gas flow schematic of space station simulator.

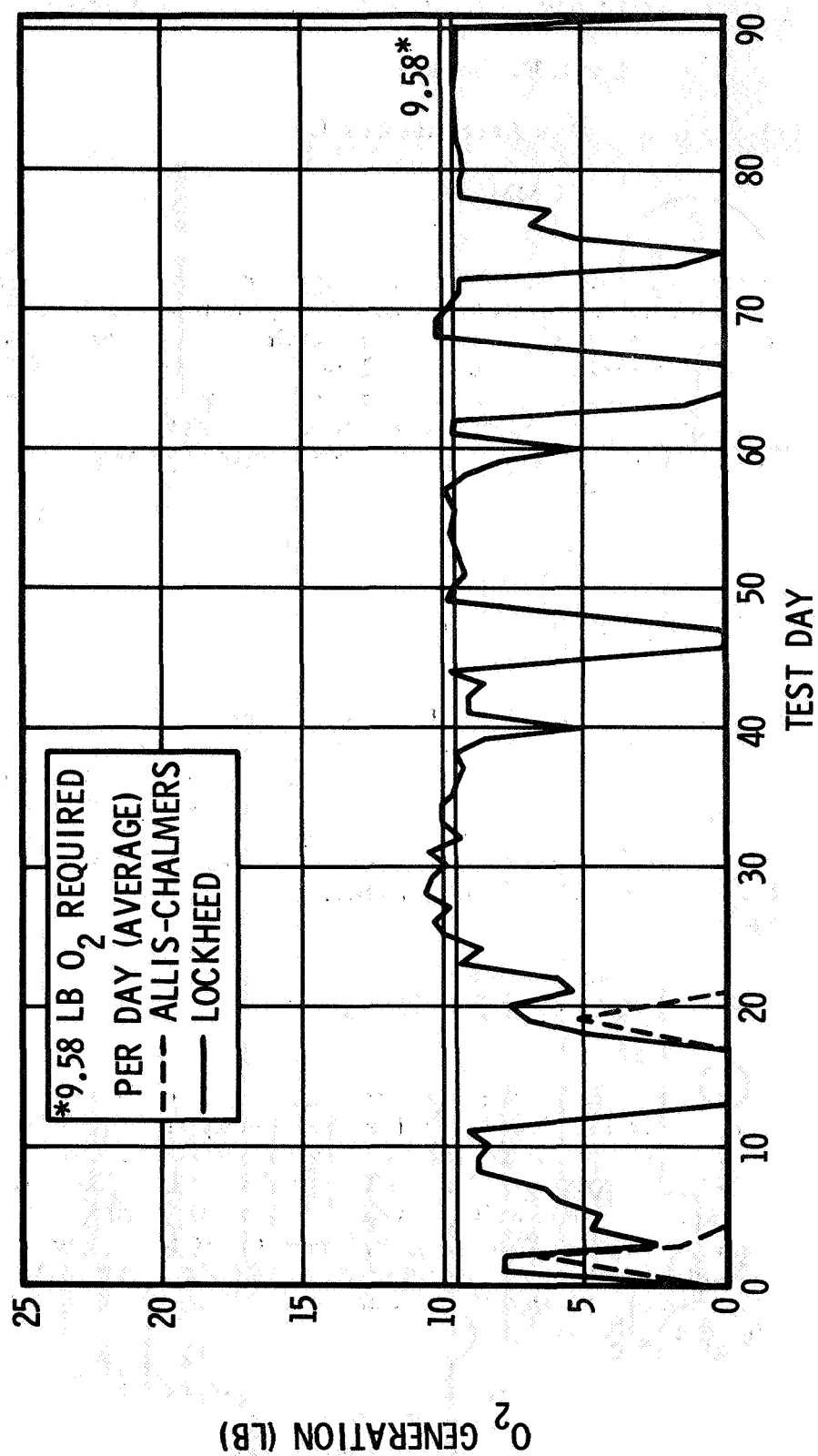


Figure 4. - Oxygen generation.

OPERATIONAL CHARACTERISTICS OF A TWO-GAS CONTROLLER

By J. F. Harkee

McDonnell Douglas Astronautics Company

SUMMARY

A system for controlling and metering the supply of atmospheric gases to the Space Station Simulator during the recent 90-day manned test functioned successfully. A four-gas mass spectrometer was utilized to generate the control signals to the atmospheric controller. The controller added 862 lb of oxygen and 279 lb of nitrogen to the Space Station Simulator during the test. During most of the test, the oxygen partial pressure was controlled within ± 0.5 mm Hg of the control setpoint and the nitrogen partial pressure within ± 8 mm Hg. The reduced accuracy of the nitrogen channel was apparently due to the higher than predicted cabin leakage associated with a low control loop gain, and can be improved by simple design modifications.

INTRODUCTION

One of the life support systems tested in the SSS during the manned 90-day test was the two-gas atmosphere supply subsystem. This unit functioned by adding fixed pulses of oxygen and nitrogen to the atmosphere. The pulse frequency is controlled by an electronic comparator signal which is proportional to the difference between the sensor output and a level representative of the preselected control point. The quantity of gas added is measured by counting the pulses. The operational characteristics observed during the manned testing are presented.

DESCRIPTION

The flight-type two-gas atmosphere controller is a second-generation unit stemming from the controller developed for the 60-day test (reference 1). A feature added to the unit in addition to compact packaging and miniaturized electronics is the capability of the unit to accept transducer signals from alternate sources. This allowed the unit to operate primarily from a four-gas mass spectrometer developed by Perkin-Elmer, or in a backup mode using a self-contained polarographic oxygen sensor for oxygen control and an absolute pressure transducer for nitrogen control. A schematic diagram of the control system is presented in figure 1.

Except for the transducer circuits, the oxygen and nitrogen supply circuits are identical (See figure 1). A transistorized, chopper-stabilized dc amplifier having very low noise level is used as an integrator in each circuit. A 10-turn potentiometer, supplied from a regulated dc power supply, is used

to adjust the set point. Operating range of the amplifier output is 10 vdc. Shorting diodes across the amplifier feedback prevent integration of over-pressure error signals.

The amplifier output is supplied to the control coil of a precision relay which is biased to approximately 6.0 volts by a dc power supply with a diode to prevent reverse current flow. Thus, error signals integrated by the amplifier increase voltage at a rate proportional to the signal error. As the voltage reaches the 6-volt bias, current conducted through the relay coil activates the relay. When this occurs, one pole of the relay shorts the amplifier output to input, and the amplifier resets to zero. Nitrogen flow is locked out, since both amplifiers are reset when the oxygen pulse is triggered.

Another pole of the sensitive relay initiates the electromechanical timer. This timer opens the appropriate solenoid valve for the required pulse of gas and advances the pulse totalizer one count. The timer is adjustable for pulse durations to 15 sec.

The flow time for an oxygen pulse was 8.56 sec, and a nitrogen pulse was 9.62 sec. The mass flow per pulse for oxygen was 2.3×10^{-2} lb at the regulated pressure of 29.7 psia, and for nitrogen 3.83×10^{-3} lb/pulse at 34.8 psia. The pulse quantities were determined by the flow area of the controlling orifices, which were selected on the basis of the predicted use rates of about 8 lb/day of oxygen and 1 lb/day of nitrogen.

Three oxygen source modes are available to the control unit: baseline mode which accepts oxygen from the flight-type electrolysis units; backup mode which accepts oxygen from an industrial electrolyzer; and storage mode which accepts bottled oxygen. Baseline operation is the primary mode, and is implemented by a pressure switch located on the oxygen accumulator that locks out the solenoid valves of the other modes when accumulator pressure exceeds 36 psia. Should the accumulator pressure drop below 30 psia, a low-pressure switch gives a visual and audio warning signal that the source pressure is approaching a level that will not support sonic flow through the metering orifice. The audio warning may be silenced by depressing an acknowledge switch, and the unit manually switched to the backup mode. When the oxygen accumulator pressure is built up to 36 psia, the unit automatically returns to baseline mode. In order to provide a record of the oxygen quantities from each source, the mode switching circuitry also switches the pulse signal to respective counters.

The pneumatic portion of the unit contains the source solenoid valves, gas pressure regulator and regulated pressure gage, pulse solenoid valves, and orifices.

OPERATIONAL RESULTS

During the initial week of the test it became evident that cabin oxygen partial pressure as indicated by the four-gas mass spectrometer was not in agreement with that indicated by the gas analysis console (GAC). The oxygen level control on the atmosphere controller was decreased to bring the oxygen to the specified level as indicated by the GAC. In addition, efforts were started to verify the analysis of the calibration gas used for the GAC and the mass spectrometer. This analysis of calibration gases revealed that the oxygen content of the GAC calibration gas was about 2 percent lower than the vendor's certification stated. This resulted in an actual oxygen partial pressure in the cabin of 145 mm Hg as compared to the desired level of 155 mm Hg. The set point oxygen level of the atmosphere controller was accordingly increased and oxygen was manually added from high-pressure storage on day 7 of the test in order to bring the oxygen level to the proper 155 mm Hg level. Figure 2 presents the average oxygen partial pressure level throughout the test, and the oxygen level perturbations of the first week are evident. Figure 2 also shows that the oxygen stayed within ± 0.5 mm Hg of the control level for the remainder of the test. Nitrogen partial pressure throughout the run stayed within the limits of 330 ± 8 mm Hg after the transients of the first few days settled out. The dips in nitrogen partial pressure indicated in figure 3 for days 8 and 12 resulted from leakage through the garbage can lid to the annulus. The dip in nitrogen partial pressure indicated on test days 28, 29, and 30 is attributed to leakage through the pass-through port while replacing the catalyst in the Sabatier reactor. The relatively large fluctuations in nitrogen partial pressure are partially due to the leakage being considerably higher than expected. The low mass flow per pulse resulted in many more pulses to correct an error than desirable. The input circuit sensitivity was also much lower than that for the oxygen channel. Improvements in these parameters would result in much more accurate nitrogen partial pressure control.

Figure 4 presents a record of total atmosphere pressure showing both the minimum and maximum pressures recorded for the day. This figure also reflects the dips in nitrogen partial pressure previously described. Figure 4 also reflects the difference in operation of the solid amine unit (before day 81) and the molecular sieve unit (days 81 to 90). The lowering in total pressure is attributed to a decrease in cabin humidity and a lesser decrease in carbon dioxide partial pressure.

One feature of the oxygen circuit design caused a loss of accuracy in the mass flow measurement feature of the two-gas control. On periods of high oxygen demand, which occurred regularly during the crew's morning exercise period, the Lockheed electrolysis unit was unable to maintain accumulator pressure. The low-pressure alarm would sound at 30 psia, and crewmen could either manually switch to the backup supply, or wait until a lower pressure was reached. When switched to the backup supply, the absence of demand on the O_2 accumulator results in a rapid buildup in pressure with automatic switchover to the primary source. In this event, the accumulator would again be depleted, and so on. Frequently the crew delayed manual switchover to the backup supply to avoid repeated requirements, until

the accumulator pressure had dropped well below that required to maintain the regulated pressure to the sonic orifice. As a result, the mass flow indicated by the pulse counter was frequently larger than the actual flow. Changes in the switchover logic should be made to provide automatic change in both directions, with a wider band between switching points to allow longer periods of accumulator recharging. Reduction in oxygen channel sensitivity would also reduce the response to transient oxygen demands. The resulting loss in oxygen channel accuracy would be quite acceptable.

No malfunctions requiring corrective action occurred at any time on the flight type two-gas control. A Beckman polarographic oxygen sensor was changed once during the mission as the original sensor had lost sensitivity. Since the mass spectrometer signal was used as input to the two-gas control, the polarographic sensor was not actually required, but was operated in order to obtain test experience.

CONCLUSIONS

The flight-type controller and sensors functioned properly throughout the test, having no malfunctions and requiring no unscheduled maintenance.

The control accuracy was very good on the oxygen channel, holding within ± 0.5 mm Hg (± 0.3 percent) of the set point during most of the period. Accuracy on the nitrogen channel was not as good, being ± 8 mm Hg (± 2.4 percent) over the major portion of the test. This can be improved considerably by increasing the input amplifier sensitivity and the flow control orifice size.

The mass flow measurement accuracy was compromised by the switchover logic in the oxygen channel, which required frequent manual attention during periods of high demand. An automatic switchover to backup supply, an increase in the differential pressure required to switch back, and a reduction in oxygen channel sensitivity would improve this operation as well as reduce transient demands on the electrolysis unit.

REFERENCE

1. J.K. Jackson: Development of Automatic Controls for a Two-Gas Atmospheric Supply System. Presented to the 36th Annual Scientific Meeting of the Aerospace Medical Association, New York City, New York. April 1965.

ATMOSPHERE SUPPLY CONTROL SUBSYSTEM

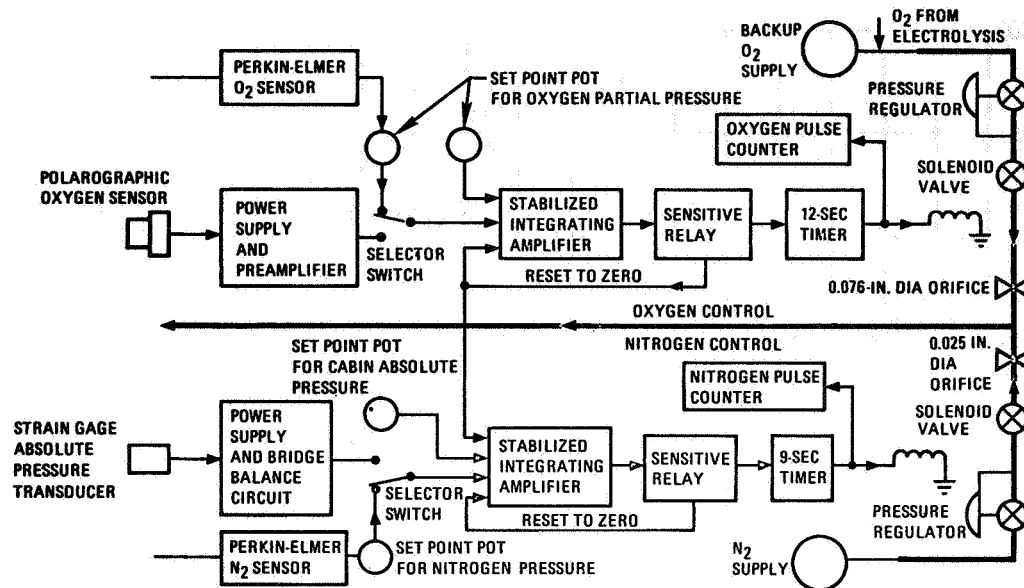


Figure 1

OXYGEN PARTIAL PRESSURE

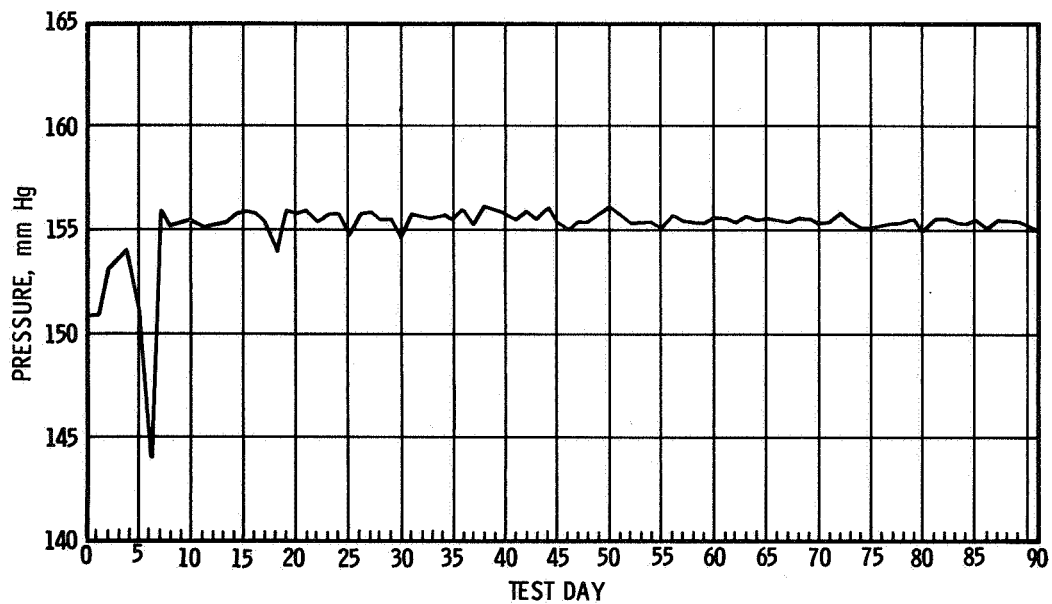


Figure 2

NITROGEN PARTIAL PRESSURE

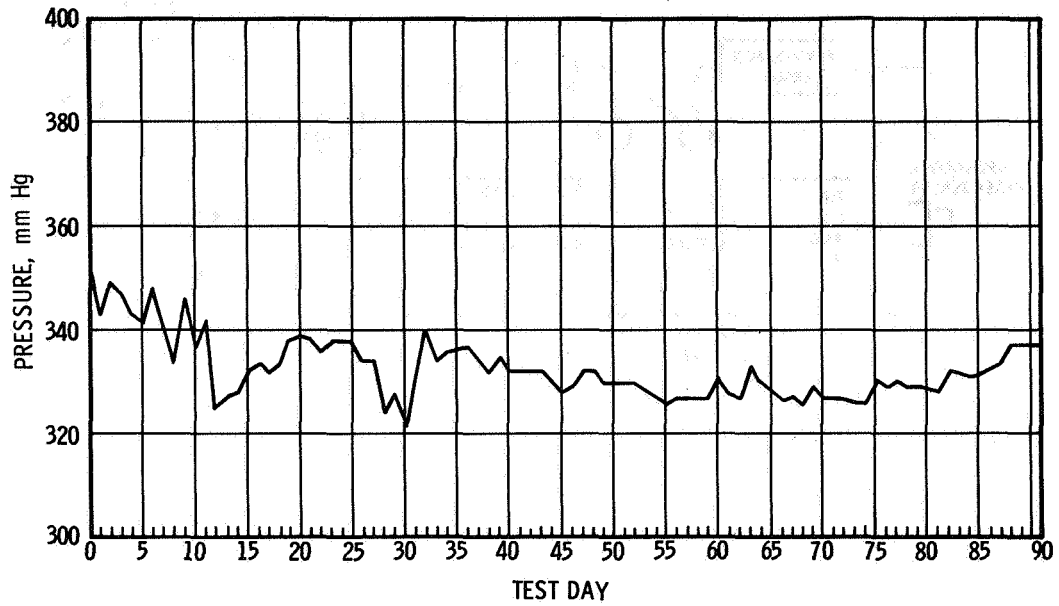


Figure 3

TOTAL ATMOSPHERE PRESSURE

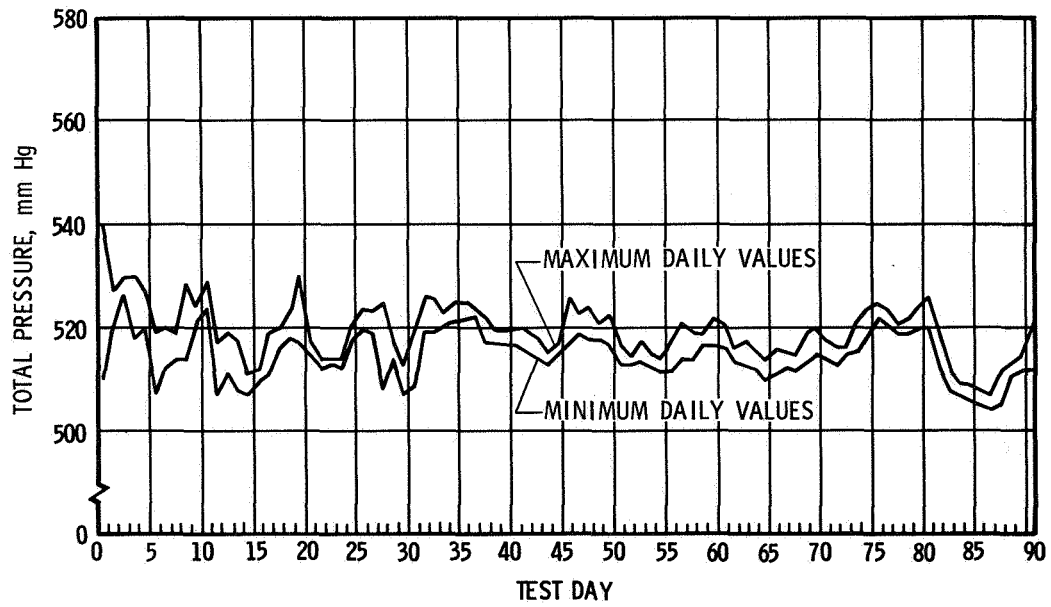


Figure 4

LOCKHEED
ELECTROLYSIS SYSTEM FOR THE
NINETY-DAY MANNED TEST

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Barbara M. Greenough

LOCKHEED MISSILES & SPACE CO.

INTRODUCTION

The Lockheed electrolysis system for the ninety-day test was designed as a back-up system to operate either inside or outside the McDonnell-Douglas Space Station Simulator. The system was designed, where possible, to meet the same interface requirements as the vapor feed unit scheduled for use in the ninety-day test. The Lockheed unit provides oxygen automatically on demand at a design rate of 8.0 lb/day. Startup and shutdown of the system can be accomplished quite rapidly and are manual operations except for automatic safety shutdown. Safety status indicators are provided on the front panel for performance monitoring. The unit is shown in Figure 1.

The program to design, fabricate, test and deliver a back-up electrolysis system for the ninety-day test was accomplished in four months. The program was initiated on 1 January 1970. The system design and system safety review was completed by the end of the first month. System fabrication was completed by mid-March. Component, subsystem and system development checkout tests and acceptance tests were completed by the end of April. The hardware was delivered to McDonnell-Douglas on 5 May 1970.

SYSTEM DESCRIPTION

The Lockheed water electrolysis system shown in Figure 1 features liquid, water feed into a circulating electrolyte. This concept was selected because of its operating advantages in the areas of water balance, temperature control and effluent gas water vapor content. With direct injection of water into the electrolyte, rapid changes in gas flow requirements can be easily accommodated. The circulating electrolyte also provides the opportunity for active temperature control which improves the ability of the system to operate over a wide variety of conditions and enhances system reliability. Another feature of the circulating electrolyte with active temperature control is that the dew point of the effluent gases can be maintained below room temperature, thus eliminating the need for condensers and phase separators. A schematic of the system, depicting the major elements, is presented in Figure 2, and the following discussion describes these elements.

Electrolysis Modules

The generating unit consists of four electrolysis modules, each containing 16 cells connected hydraulically in parallel and divided electrically into two 8-cell banks. Cells within an 8-cell electrical bank are connected in series. Peripheral manifolding within the module provides separate paths for electrolyte circulation, oxygen and hydrogen discharge, and nitrogen purge. Differential pressure control is used to maintain gas-liquid phase separation across absorbent matrices contiguous to the electrodes. Three modules are required for normal operation; the fourth module is provided for redundancy.

Accessory Equipment

The electrolyte leaving the modules passes over temperature sensors which control the electrolyte cooling and actuate the automatic shutdown safety circuit in the event of an overtemperature condition. The electrolyte then passes through a bubble separator which removes gas bubbles from the electrolyte which may have developed as a result of dissolved gases in the feed water. A magnetically driven centrifugal pump is used to circulate the electrolyte through a heat exchanger. The flow of coolant to the heat exchanger is controlled by a temperature sensor in the electrolyte. A closed reservoir is used in the electrolyte circuit to provide system pressure through the use of a diaphragm and spring. Water feed is controlled by the reservoir diaphragm position. As water is consumed and hence electrolyte volume reduced, a signal is sent to the water feed solenoid and gear pump which allows water to be added to restore the initial liquid volume. The feed water is passed through an ion exchange resin to remove ionic species that would tend to build up in concentration if allowed to enter the electrolyte. The electrolyte reservoir also includes safety functions that shut the system down in the event of a loss of electrolyte due to a leak or excessive electrolyte due to a failure of the water feed systems.

The electrolyte leaving the reservoir is then routed to each of the electrolysis cell modules. Gas generated by the electrolysis cells passes through differential pressure controllers which maintain the correct electrolyte interface at each electrode. The differential pressure controllers sense electrolyte pressure in the module and gas pressure in the module and throttle the gas effluent to maintain a gas pressure 25 inches of water greater than the electrolyte pressure.

Hydrogen is delivered from the electrolysis modules at approximately 9 psig. Oxygen discharged from the electrolysis modules at approximately 9 psig is pumped to 21-27 psig using a diaphragm pump. A pressure regulator across the pump maintains the pump suction pressure at 5 psig.

Nitrogen purge is provided to maintain gas-liquid differential pressure during startup and shutdown. When this function is actuated, either manually or automatically during safety shutdown, inlet and outlet solenoid valves in the hydrogen and oxygen discharge lines open, allowing nitrogen to flow through the oxygen and hydrogen chambers of the electrolysis modules. A micrometer valve is used to adjust the nitrogen flow rate.

AUTOMATIC CONTROLS

The electrolysis system is designed to function in an automatic mode during normal operation, except during manual startup and shutdown. The individual control functions are described in the following paragraphs.

Temperature Control

Control of the electrolyte temperature, necessary because of the waste heat generated in the electrolysis reaction, is accomplished by using a thermostat in the electrolyte discharge line from the modules to provide a control signal to a coolant solenoid valve. On demand, the solenoid valve opens to allow coolant to flow through the electrolyte heat exchanger. The flow rate is set by a flow control valve. Control of the electrolyte temperature also provides control of the dewpoints of the generated oxygen and hydrogen. The thermostat provided in the electrolyte oxygen generator has a switch-closure setting of 75°F. During normal operation, the dewpoint of the product oxygen will be no greater than 75°F; the hydrogen dewpoint of the product oxygen will be approximately 40°F.

Coolant flow to the electronics cold-plate is continuous and is manually adjusted with a flow control valve.

Water Feed

Water balance in the circulating electrolyte is maintained by controlling the electrolyte volume. A pair of micro switches in the electrolyte reservoir actuate high- and low-level switches in the water feed control band. A water feed cycle occurs as follows: water is consumed in the electrolysis modules causing the volume in the reservoir to be reduced. When the rolling diaphragm reaches the bottom of the control band, the water feed pump is actuated; the water feed solenoid valve opens; and the 15-second water feed timer starts. Fifteen seconds is the maximum feed time; the flow control valve is set to deliver sufficient water in approximately five seconds. As water is fed to the reservoir, the volume increases and the rolling diaphragm reaches the top of the control band. At this point, the water pump is shut off, the solenoid valve closes, the 15-second timer resets, and a 15-minute timer starts. This timer is set to run for five minutes. During this period, the water feed signal is overridden so that another water feed cannot occur until the timer resets.

Differential Pressure

Two differential pressure controllers mounted on each module are set to control the hydrogen and oxygen pressures at 25 in. H_2O above the electrolyte pressure in order to maintain gas-liquid phase separation. Each differential pressure controller is essentially a valve in operating principle, with a spring loaded valve stem attached to a rolling diaphragm. The valve seat is adjusted so that 25 in. H_2O higher pressure on the gas side of the diaphragm than on the liquid side is required to overcome the spring and open the valve.

Current Regulation and Oxygen Output Control

Each electrolysis module is provided with a current controlled switching regulator to control the DC current input. Oxygen output is a direct function of the current value. The current value is selected by automatic or manual command. These currents are maintained over a module voltage range of 13.5 to 17.5 volts and a supply voltage range of 25 - 31 volts with an efficiency greater than 75%.

Module 4 is the only module which can be operated in the standby mode. In this mode, it can only be operated at the low current value. In the on mode, all modules can be manually operated at either high or low current. In the normal automatic mode of operation, a pressure switch in the oxygen discharge line determines the high or low current value. In this latter mode, all modules which are on will automatically switch to the low current value at 27 psig and to the high current value at 21 psig.

Safety Circuits

Safety circuits are provided to automatically shut down the system under normal operating conditions. In an automatic shutdown, electrolysis module power is turned off, the electrolyte pump, water feed system and system reset are turned off, nitrogen purge to the modules comes on, and the cause of shutdown is indicated on the front panel.

The following safety circuits are provided:

Module Temperature - A temperature sensor is located in each module, in contact with an end electrode. These thermostats have two switch-closures: one at 85°F and the second at 100°F. The 85°F point provides a warning signal; the 100°F point signals automatic system shutdown. Any one of the four temperature sensors can actuate the shutdown.

Gas Pressure - The oxygen and hydrogen discharge lines from the modules each contain a pressure switch set to actuate automatic shutdown if the pressure reaches approximately 13 psig.

Electrolyte Volume - Switches located in the electrolyte reservoir are actuated if the electrolyte volume in the reservoir exceeds a 3% change in the total electrolyte volume.

Hydrogen Detector - A hydrogen detector is located directly over the electrolysis modules and will signal automatic shutdown if the hydrogen concentration reaches 0.8%.

Power Interruption - The loss of input power to the unit, even if momentary, will automatically put the system in the shutdown mode from which it will have to be manually restarted.

CHECKOUT TEST RESULTS

During checkout tests of the system at Lockheed two problems evolved. One of these was with the closed reservoir and the other was with the nitrogen purge system. These problems will be discussed in this section.

The unit utilized a zero-gravity bubble separator and closed reservoir water feed system. These two components made the design completely gravity independent. The bubble separator, which was the key element in the zero-gravity operation had been successfully bench tested for ninety days. However, the closed reservoir water feed system was a new component. During checkout tests of the unit, the spring in the closed reservoir caused an unexpected pressure increase which damaged the bubble separator membrane. The spring was operating in the region of buckling, which produced an erratic spring rate. To correct this, it required a redesign and fabrication of a new spring and repair of the bubble separator. The delivery schedule did not allow sufficient time for this, and hence an available one-gravity bubble separator and water feed system was substituted. This unit consisted of a reservoir with floats for water feed and system volume safety control. Electrolyte pressure was achieved by applying a controlled nitrogen pressure to the top of the reservoir.

The spring for the closed reservoir was subsequently increased to a larger diameter and a nylon spring guide was provided. The bubble separator was reworked and these two components have been successfully bench tested in an electrolysis system located at Lockheed.

The second problem that occurred during the development testing was mixing of hydrogen and oxygen in the nitrogen purge line. This was observed when gas samples were being obtained at various points in the system. The original configuration for the nitrogen purge supply was a solenoid supply valve branching to two nitrogen supply lines with check valves. These lines supplied pressure to the hydrogen and oxygen passages of the electrolysis modules. The mixing of hydrogen and oxygen occurred at a point between the two check valves and was due to the fact that the check valves were not providing a positive seal. The situation was corrected by providing two nitrogen supply solenoid valves, one for the hydrogen and one for the oxygen gas passages. Check valves with a high cracking pressure were also provided in these lines. After these modifications were made, the problem did not

reoccur.

ACCEPTANCE TEST RESULTS

At the conclusion of the checkout tests conducted at Lockheed, a continuous 100 hour acceptance test was conducted. During this acceptance test, the system operated successfully in a continuous hands-off mode. Oxygen was supplied to an accumulator which was venting at a rate of 8.0 lb/day. The unit automatically cycled from high to low current mode as required to achieve an 8.0 lb/day oxygen production rate. The performance results of the 100 hour acceptance test are presented in Table I, indicating the required and demonstrated characteristics. In all cases, the gas purity exceeded the requirements and there was no admixing of hydrogen and oxygen detected.

NINETY-DAY TEST RESULTS

The electrolysis system was delivered to McDonnell-Douglas on 5 May 1970. The unit was installed outside of the cabin simulator to be used as a back-up system.

Test Installation

During installation, two additional problems developed. The first of these problems was the failure of the electrolyte to coolant heat exchanger. The probable cause of this failure was fatigue of the heat exchanger due to rapid cycling of the coolant solenoid valve. The temperature switch that controlled the coolant solenoid was changed during the installation because the original switch did not meet the ORI requirements. The new switch was bi-metallic and did not provide a sharp closure which caused the solenoid valve to chatter, resulting in hydraulic hammer on the heat exchanger. The problem was rectified by replacing the heat exchanger and modifying the control circuit to filter out the switch noise. No subsequent problems were experienced with the heat exchanger.

The second installation problem occurred during a loss of 28 VDC supply power to the unit. When this occurred, the residual cell voltage was impressed on the nitrogen purge solenoid valve, which prevented them from opening. This problem was rectified by adding a relay which opened the circuit to these valves during a loss of input power.

Ninety-Day Test - Lockheed System Status

The status of the Lockheed electrolysis system is presented in Figure 3. The system operated for 70 days during the ninety-day test period. The bulk of this operating time was spent in the primary mode during which the unit was supplying hydrogen and oxygen to the chamber. Some periods of operating time were spent in the standby mode where the system was operating but was not providing oxygen and hydrogen to the chamber. For twenty of the ninety days, the system was turned off for corrective maintenance.

Failure Analysis

During the ninety-day test, failures occurred which required corrective action. These failures are presented in Table II. The table does not include failures of test support equipment unless they resulted in a subsequent electrolysis system failure. The period of time that the unit was off is also indicated on the table. This was not the time required for maintenance since, on some occasions, time was required to obtain new parts. None of the failures that occurred during the ninety-day test were major in nature, nor did they indicate a need for alteration of the basic concept. The failures primarily were associated with the accessory equipment and could have easily been avoided if reasonable development test time had been available prior to delivery of the unit. The only failure involving the electrolysis cell modules was caused by a problem with equipment that the electrolysis cell interfaced with. This occurred when the back pressure on the hydrogen supply was increased to a point near the matrix breakthrough pressure. This was done periodically and eventually resulted in a matrix failure. The applied pressure was slightly less than the overpressure switch setting, however, breakthrough occurred at a slightly lower pressure than was anticipated due to the cyclic nature of the pressure pulse. This problem would not have occurred if the overpressure switch setting had been reduced. Loss of current control on the 77th day caused the unit to supply oxygen at a rate slightly below the 9.6 lb/day required by the chamber but at a rate well above the 8.0 lb/day design point.

CONCLUSIONS

The results of the ninety-day test have indicated that the circulating electrolyte system offers some operational advantages. The system demonstrated the ability to operate automatically for long periods of time with no operator adjustments required. The system was also able to respond to wide variations in gas demand. Active temperature control provided stable operation with no effluent gas water removal required. As a result of the experience gained in the ninety-day test, a number of design improvements have been identified which would increase system reliability and maintainability for zero-gravity operation. These improvements include:

- o Provisions for replacing circulating fluid loop assemblies without breaking integrity of fluid system. A multi-man system would consist of several fluid loop assemblies.
- o Minimizing lines and fittings through additional internal manifolding.
- o Reduce sensitivity to downstream hydrogen and oxygen pressure pulses. Subsequent to the ninety-day test, cells have been built and tested with increased matrix support which prevents matrix damage when a gas breakthrough occurs. This eliminates the need for matrix replacement. Additional work is being conducted on higher breakthrough matrix supports.

Based on these design improvements, it is felt that this system is a primary candidate for future space electrolysis system applications.

TABLE I
ACCEPTANCE PERFORMANCE TEST RESULTS

PARAMETER	REQUIRED	DEMONSTRATED
OXYGEN PRODUCTION	8.0 LB/DAY	8.0 LB/DAY
OXYGEN PURITY	99.7%	> 99.95% *
ADMIXED HYDROGEN	0.1%	< 0.05% *
HYDROGEN PURITY	99.3%	99.89%
ADMIXED OXYGEN	0.1%	< 0.05% *
SYSTEM OUTGASSING	-	TOTAL HYDROCARBONS < 20 ppm*
	-	CARBON MONOXIDE < 2 ppm*
	-	METHANE < 2 ppm*
POWER CONSUMPTION	-	1200 WATTS
POWER CONVERSION EFFICIENCY	-	75%

* LIMIT OF DETECTION

TABLE II
NINETY-DAY TEST FAILURE ANALYSIS

TEST DAY	PROBLEM*	CAUSE	CORRECTIVE ACTION
4	o N ₂ PURGE FITTING FAILED	o OVERTORQUING	o REPLACED AND RETORQUED
10	o LOSS OF CURRENT CONTROL, MODULE 1	o ELECTRICAL INTERFERENCE BETWEEN OSCILLATORS	o ADDED SHIELDING
12 - 18	o N ₂ PURGE SOLENOID LEAKED	o BUNA-N SEATS DEFORMED	o INSTALLED VITON SEATS
24	o MODULE 3 OVERTEMPERATURE SWITCH FAILED CLOSED	o SHIFT IN SWITCH CALIBRATION	o DISCONNECT SWITCH AND RE-PLACE TEST DAY 46
41	o MODULE 4 OVERTEMPERATURE SWITCH FAILED CLOSED	o SHIFT IN SWITCH CALIBRATION	o DISCONNECT SWITCH AND RE-PLACE TEST DAY 46
45 - 48	o LEAKAGE OF KOH FROM TEMPERATURE SENSOR	o DEFECTIVE "O" RING IN SENSOR	o REPLACED "O" RING
	o SHORT CIRCUIT IN MODULE 1	o KOH CRYSTALS BRIDGING ELECTRODES EXTERNALLY CAUSED BY KOH LEAK	o REPLACED DAMAGED PARTS IN MODULE 1
60	o N ₂ PURGE FITTING FAILED	o OVERTORQUING	o REPLACED ALL N ₂ PURGE FITTINGS AND RETORQUED
	o INTERNAL 28 VDC POWER SUPPLY FAILURE	o EXCESSIVE OPERATING TEMPERATURE	o REPLACED POWER SUPPLY AND RELOCATED TO COOLER ENVIRONMENT
63 - 66	o GAS BUBBLES IN ELECTROLYTE LEAVING MODULE 2	o NOT DETERMINED AT THIS TIME	o MATRIX MATERIAL REPLACED IN MODULE 2
73 - 74	o GAS BUBBLES IN ELECTROLYTE LEAVING MODULES 1, 3 AND 4	o OVERPRESSURE DUE TO SETTING OF CHAMBER H ₂ RELIEF VALVE	o RESET CHAMBER H ₂ RELIEF VALVE TO PROPER VALUE AND REPLACED MATRIX MATERIAL
	o O ₂ DIFFERENTIAL PRESSURE CONTROLLER STEMS CRACKED OR FRACTURED	o PRESSURE CYCLING OF O ₂ PUMP	o REPLACED STEMS WITH HIGHER STRENGTH MATERIAL
77	o LOSS OF CURRENT CONTROL MODULE 1	o NOT DETERMINED AT THIS TIME	o UTILIZE BACK-UP MODULES

* ONLY SHUTDOWNS INVOLVING ELECTROLYSIS SYSTEM FAILURES.

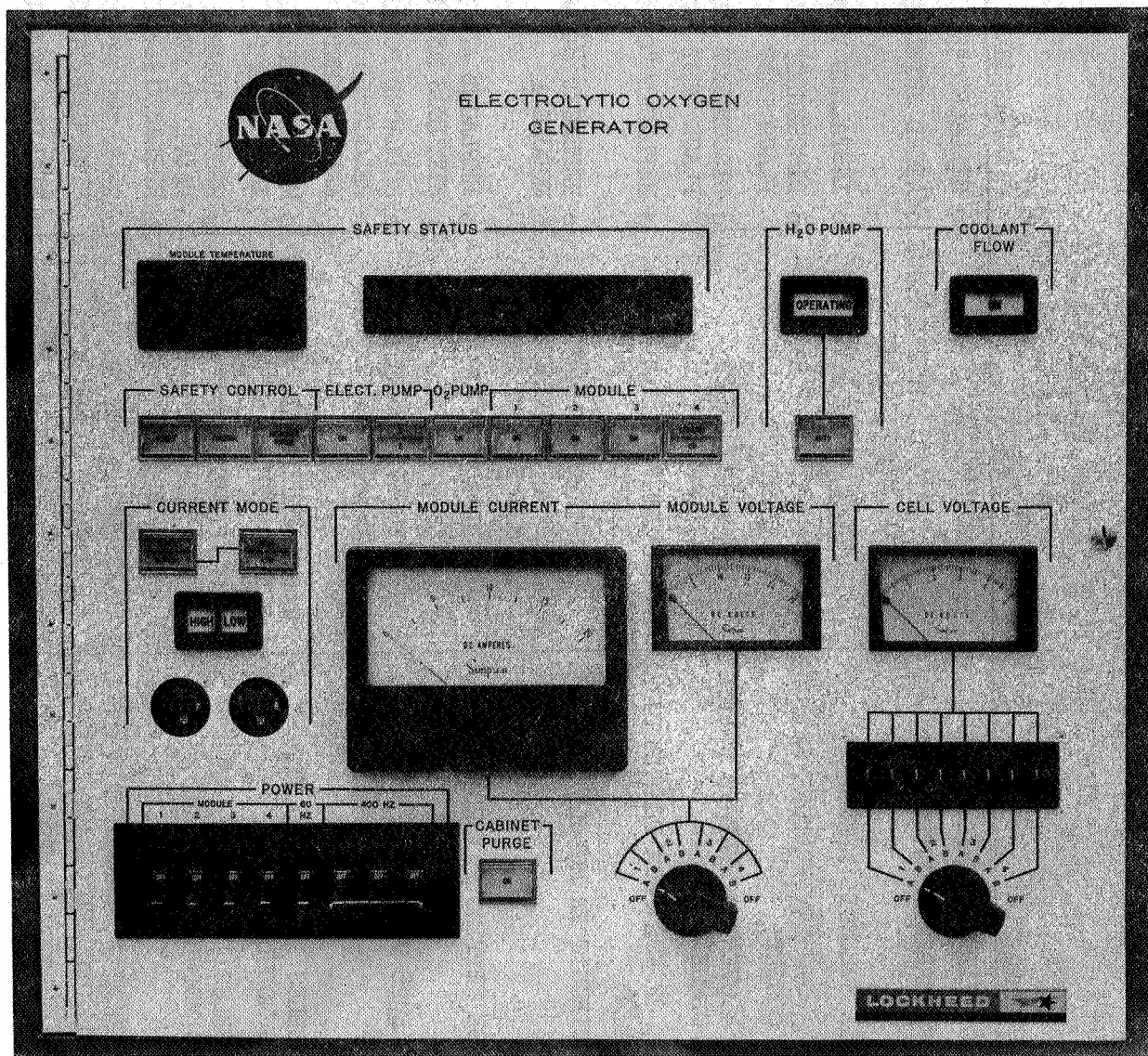


Figure 1.- Lockheed electrolysis system.

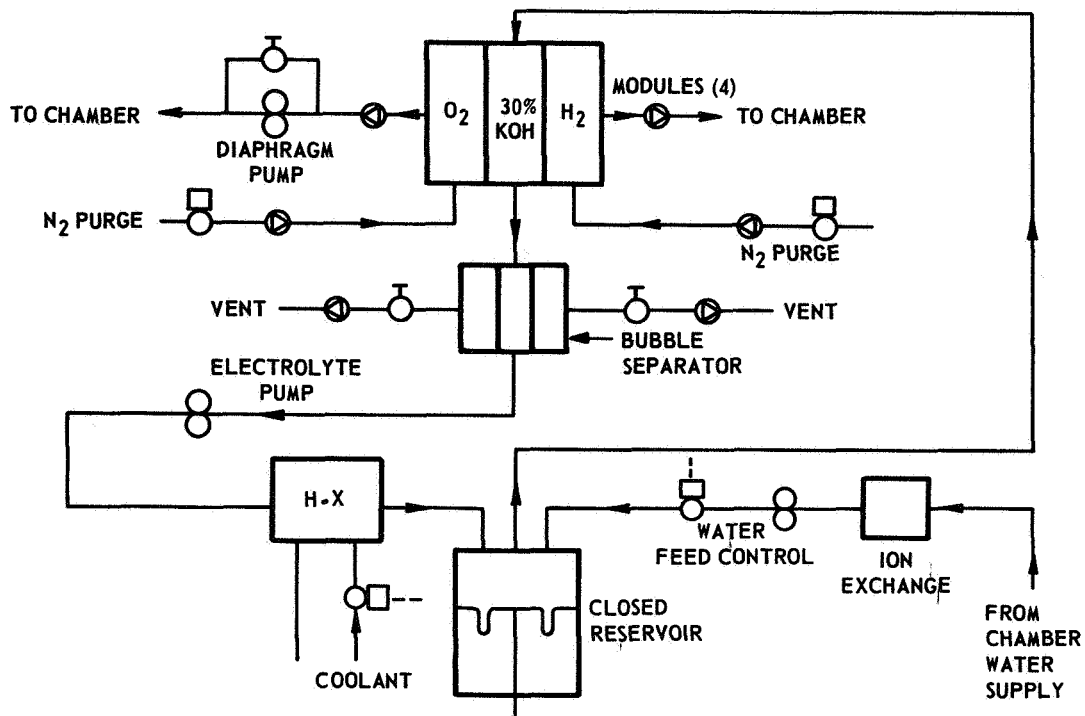


Figure 2.- System schematic.

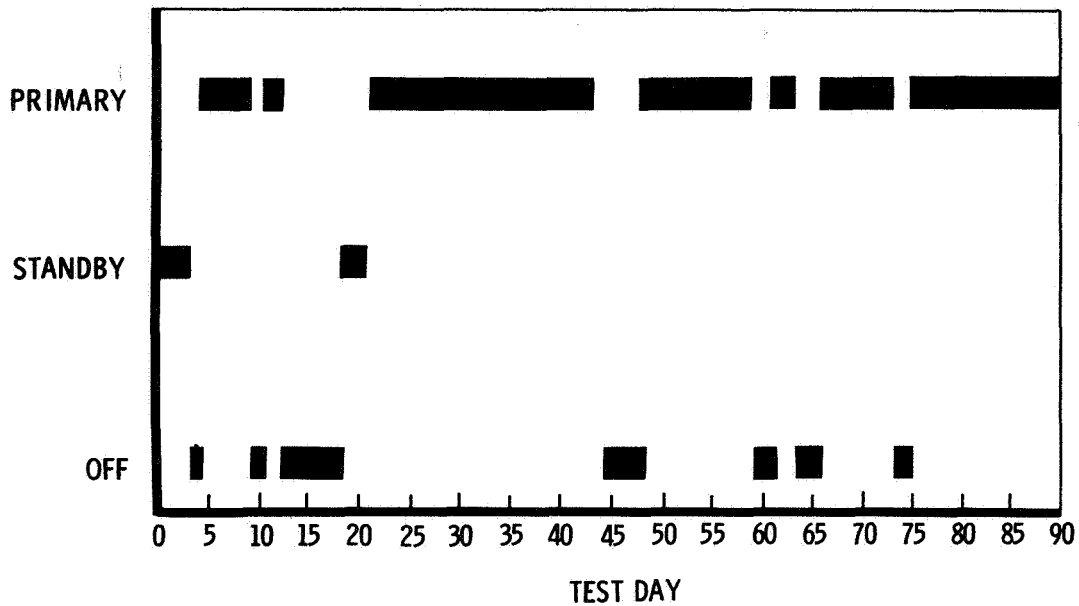


Figure 3.- Ninety-day test Lockheed system status.

EVALUATION OF A FOUR-GAS MASS SPECTROMETER

USED FOR ATMOSPHERIC CONTROL DURING THE

NINETY-DAY TEST

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SUMMARY

The design and performance of a Mass Spectrometer Atmospheric Sensor System which was utilized for monitoring and control of the atmosphere of a manned space station simulator during a 90 day test is reviewed. The instrument was a modified Two Gas Atmosphere Sensor System which was operated with a new closed loop electronics control system for improved long term stability. Based upon calibration verification data taken during the 5-day and 90-day runs, the instrument was demonstrated to hold its calibration within 1% for nitrogen, 2% for oxygen, and 3% for carbon dioxide for a period of 132 days. It also monitored water vapor partial pressure. The output signal from the oxygen channel was employed by an atmosphere control system for maintaining the oxygen partial pressure of the space station simulator. The instrument demonstrated its ability to perform reliably and its potential value as equipment for ECS applications.

INTRODUCTION

In 1965 a phased program aimed at the development of a mass spectrometer system for monitoring the major constituents of a buffered two gas atmosphere as well as the primary metabolic products of respiration was initiated with Langley Research Center. The Two Gas Atmosphere Sensor System, a single focusing magnetic sector mass spectrometer, evolved from this program, and was capable of continuously monitoring nitrogen, oxygen, carbon dioxide, and water vapor. An engineering test model and four prototype units were fabricated on this program. One of these units is shown in Figure 1. These instruments have been employed in several applications for atmospheric and respiratory measurements in various laboratories, a space station simulator, and two undersea habitats. One of these applications was in conjunction with the 60-Day Manned Space Cabin Simulator Test in 1968. At that time the Two Gas Atmosphere Sensor System was operated externally to the Space Cabin Simulator with a laboratory vacuum system, and sampled the cabin atmosphere through a capillary-bypass inlet system.

In the most recent application, the subject of this paper, one of the original instruments was refurbished, equipped with updated electronics, repackaged with a close coupled ion pump and a direct entry sample inlet system, and mounted inside the Space Station Simulator where it monitored the partial pressures of oxygen, nitrogen, carbon dioxide, and water vapor. The output signal of the mass spectrometer's oxygen channel was provided as the input to the atmospheric control system which controlled the oxygen partial pressure. The performance of the combined system was more than adequate to hold the oxygen partial pressure within the limits required for constant physiological functioning of the crew.

PRINCIPLES OF OPERATION

The Two Gas Atmosphere Sensor System is a single focusing magnetic sector mass spectrometer that is designed to provide four simultaneous outputs which are proportional to the partial pressures of N_2 , O_2 , CO_2 , and H_2O . The fundamentals of the operation of the mass spectrometer are diagrammed in Figure 2. A small quantity of the gas sample to be analyzed is continuously introduced to the mass spectrometer through a molecular inlet leak. The characteristics of this leak allow each constituent of the sample to flow through the leak independent of the other components. The resulting partial pressures within the ion source are proportional to the corresponding partial pressures in the sample environment.

The ion source performs the function of ionizing part of the gas to form charged particles which are then acted upon by the electrostatic and magnetic fields within the instrument. Ionization is accomplished by bombardment of an electron beam which is derived from a hot wire filament. The ions are repelled from the ionizing region, focused by an electrostatic lens, and passed through the ion source exit slit into the magnetic sector. A permanent magnet provides a uniform magnetic field through which the ion beam passes within the vacuum envelope. The ions are deflected into circular arcs by the magnetic field, their radii being proportional to the square root of the mass to charge ratios of the ions. Since all the ions of interest are singly charged, the radii are proportional to the square root of mass ($m^{1/2}$). Consequently, the ions are dispersed as they leave the magnetic field and are collected by four Faraday cage type collectors located along a focal plane. The collectors are attached to single pin feedthroughs that pass the current through the vacuum envelope to four electrometer amplifiers that amplify the small currents to provide output voltages which are proportional to the ion currents. The output signals are therefore proportional to their respective partial pressures. The internal vacuum necessary for operation of the analyzer is maintained by a suitable high vacuum pump, which is connected to the mass spectrometer by means of a pump tube.

The Two Gas Atmosphere Sensor mass spectrometer analyzer assembly is shown in Figure 3. The vacuum envelope, permanent magnet, single pin feedthroughs and the pump tube are clearly visible. The multipin feedthroughs that are visible in the ion source housing provide the voltages that operate the ion source filament and focusing electrodes.

REQUIREMENTS FOR THE 90-DAY TEST

The requirements for the 90-Day Space Station Simulator (SSS) application were a modified Two Gas Atmosphere Sensor to monitor the partial pressures of nitrogen, oxygen, carbon dioxide and water vapor. The principal requirements are summarized in Table 1.

The instrument was to be located within a specified volume within the SSS and to give continuous outputs within a specified tolerance for the entire 90-day period without requiring recalibration. In order to provide information for engineering evaluation of the instrument's performance, a method of making calibration verification was required. The instrument was to be provided with the necessary support equipment to maintain its internal vacuum through a power failure. Dual outputs were necessary for internal signal monitoring by meters as well as voltage outputs to be monitored by the computer system external to the simulator.

TABLE 1

Requirements for 90-Day SSS Atmospheric Sensor

Monitored Species:	H ₂ O, N ₂ , O ₂ , and CO ₂
Monitored Masses:	m/e 18, m/e 28, m/e 32, and m/e 44
Full Scale Ranges:	20 torr, 500 torr, 200 torr and 120 torr, respectively.
Total Pressure:	Nominally 10 lbf/in ² abs or 517 torr
Configuration:	Limited size consistent with available space and commercial support components.
Operating Controls:	None for normal operation. Inlet system valving for initial setup and calibration verification. Power on-off, ion pump, and emission current adjusts.
Maintenance:	None
Outputs:	Internal: four meters. Remote: four buffered, linear, zero to 5 volt.
Performance Monitors:	Anode current, ion pump current, and battery voltage.
Sample Inlet:	Sample transport line with 3 inch H ₂ O head.
Nominal Accuracy:	±2% of full scale for N ₂ and O ₂ . ±3% of full scale for CO ₂ ±5% of full scale for H ₂ O
Environment:	Compatible with operation in the Space Station Simulator

SYSTEM DESCRIPTION

The description of the 90-Day SSS Atmospheric Sensor is facilitated by considering its major system components which are: first, the sample inlet and calibration inlet system; second, the mass spectrometer subsystem including its vacuum pump; and third, the support electronics subsystem which includes the electronics required to operate the analyzer and ion pump, as well as the output circuits. A block diagram of the system is shown in Figure 4, and can be used for reference in the following discussion. The sample and calibration inlet system shown in the upper left hand corner of Figure 4 is shown in greater detail in Figure 5 and the front panel of the system is shown in Figure 6.

To simplify the system description, each part of the system referred to has been assigned an index number as shown in Figures 5 and 6. Sample gases enter the inlet system from the 1/8 inch sample line at the sample inlet point (1). The sample gas then passes through a needle flow control valve on the front panel of the instrument (2). After passing through the flow controlling valve, the sample gas goes to the mode selector valve (3) which determines the mode of operation, that is, operating in the calibration mode or the normally operating sample mode. After passing through the mode selector valve, the gas is filtered by a two stage inline filter (4). On the sample outlet, corresponding sets of filters (5) are present. The gas mixture then passes through a sample flowmeter (6) which measures the rate of gas flow through the instrument and therefore allows the pressure drops through the inlet system to be checked. After passing through the flowmeter, the sample travels past a total pressure transducer (16) and out the sample vent (17). Between the double filters the gas passes through the variable leak valve (7). This variable leak valve is fitted with a temperature control system. The heater switch (8) controls the heater for the inlet valve. The calibration gas mixture is stored in a pressure tank (9) with regulator (10). Passing through the regulator, the sample gas goes to a protection shutoff valve (14), to a needle flow control valve (15), and then to the selector valve (3). Part of the gas to be sampled (either the sample gas or the calibration gas) passes through the restriction in the leak valve and through a small diameter line (11) into the mass spectrometer (12) and finally to the ion pump (13). There is a roughing valve (25) located within the analyzer chassis for initially pumping down the instrument. The conductance of the variable leak valve can be adjusted by means of a slotted screw adjustment (28) on the front panel. The ion currents coming out of the mass spectrometer are detected and amplified by four electrometers. The electrometer outputs go to the output meters (26) and also to buffered outputs. The zero levels of the electrometers can be checked by pressing the press-to-test button (27), which cuts off the ion beams. The main power to the mass spectrometer is provided by a 28 V dc power supply, and requires a 115 volt ac input.

There is a front panel switch (18) that controls the operation of the 28 volt power supply. Other items on the front panel are the ion pump meter switch (19), and the ion pump current meter (20). These monitor the current flowing to the ion pump from the high voltage supply and therefore, indirectly monitor the analyzer pressure. There are two other meters on the front panel of the Analyzer Control Module. One of these is the battery voltage indicator (21). This indicates the stage of readiness of the emergency batteries that are used for powering the ion pump in a power off situation. The other front panel meter is the anode current meter (22). This meter measures the anode current and gives an indication of the sensitivity at which the source is being operated. The anode current may be adjusted only in open loop mode by the anode current adjustor potentiometer (23). The mode of operation, open or closed loop, is controlled by a selector switch (24) on the front panel.

An important feature of the system is the closed loop mode of operation which automatically compensates for any common mode variations. The four electrometer outputs are scaled to provide signals that are all proportional to pressure with the same volt per torr sensitivity and are summed to give a "total pressure" signal. Since the four components of interest comprise essentially all the atmosphere, this signal can be compared with the output of a total pressure transducer, which is reflecting the true pressure seen by the sample inlet system. The resulting error signal represents the sensitivity error of the mass spectrometer. This signal is fed back to the emission regulator that controls the level of ionizing electron current in the ion source and, thereby, the levels of the ion currents which are detected at the collectors. In this way the summation of the partial pressures is held at the prevailing ambient pressure level and, consequently, common mode variations due to such factors as changes in the inlet leak conductance or ion source sensitivity are eliminated. This method of operation represents a significant improvement in mass spectrometers design and allows a high level of accuracy to be maintained for a long period of time.

Other elements of the system, which are shown in Figure 4, are the power supplies that provide voltages to the ion source, the ion pump and its high voltage power supply, the power supply system, the front panel control and monitoring functions, and the output buffer amplifiers.

The complete 90-Day SSS Atmospheric Sensor is shown in Figure 7 and the internal construction of the upper and lower bays is shown in Figures 8 and 9, respectively. The upper bay contains the mass spectrometer, ion pump, their support electronics, the sample inlet and calibration inlet systems, and the calibration gas supply. The lower module houses the main power supply, the battery pack and charger, the buffer amplifiers, output and monitoring meters, and the buffer amplifiers and pressure transducer power supplies.

CALIBRATION

The Atmospheric Sensor was calibrated by use of a calibrated gas mixture of N₂, O₂, and CO₂. In order to calibrate the instrument as nearly as possible to the expected operating conditions, the calibration gas was admitted to a laboratory inlet system in which the pressure was held at 10 lbf/in² abs (517 torr), and from this reservoir it was introduced into the mass spectrometer inlet system. The volt per torr sensitivity at the electrometer amplifier output of each channel was computed and this information was utilized to adjust the summing resistors so that the current arriving at the summing junction of the summing operational amplifier from each channel has the same ampere per torr sensitivity. Then the gains of the buffer amplifiers are set so that the proper full scale value for each channel is achieved at five volts. During the dry gas calibration the pressure was exercised between 400 and 634 torr to verify that the channels were tracking pressure. This is a $\pm 22.6\%$ pressure variation which is much greater than the expected variation of the space station simulator atmospheric pressure. The final calibration data over this pressure range is shown in Table 2.

TABLE 2

Table of Calibration Errors at Final Calibration

Pressure	Error		
	N ₂	O ₂	CO ₂
400 torr	+0.37%	-0.85%	-2.86%
517 torr	-0.01%	+0.01%	+0.31%
634 torr	-0.29%	+0.58%	+2.87%

The water vapor channel was calibrated by allowing the inlet system to sample laboratory air and comparing the H₂O electrometer output with the partial pressure, as computed from the relative humidity indicated by a wet bulb - dry bulb Mason's form hygrometer. Since the instrument was sampling at one atmosphere during this test, the variable inlet leak valve was closed down to maintain the normal internal partial pressures. The water sensitivity was compared with the nitrogen sensitivity as determined from the air composition and this data was utilized to set the water vapor channel summing resistor and buffer amplifier gain.

OPERATIONAL RESULTS

During the 5-day test run the calibration of the Atmospheric Sensor was verified twice by admitting a calibration gas sample. During the first verification the gains of the buffer amplifiers for the dry gas channels were reset. The oxygen buffer amplifier gain had somehow shifted during the process of shipment, inspection, and installation. The other buffer amplifiers were

very close to their proper values. The data from this calibration verification and a second one taken later during the run is shown in Table 3. In both cases the error is less than one percent on all dry channels.

During the 5-day test it was found that the water vapor channel was reading high compared with the Cambridge Dew Point Hygrometer. The dew point indicator was reading 11.3 torr while the mass spectrometer was reading 23.1 torr, with a buffer amplifier output of 4.68 volts. Just prior to the end of the run the buffer amplifier was adjusted to give an output of 2.82 volts based upon an 11.3 torr partial pressure and a desired system gain of 20 torr per 5 volts. This correction gave the proper water output, but it did not correct the summing resistor for the water channel, which was also apparently in error. One effect of this adjustment is seen in the data presented in Figure 10. This shows the error between the sum of the partial pressures as indicated by the mass spectrometer, and the total cabin pressure as measured by the Wallace-Tiernan gage. During the 5-day run the sum of the partial pressures agreed with the total pressure within one percent or better except for the final reading, which was 2.9 percent low. This final value was taken after the water vapor channel was readjusted. This additional 2 percent error amounts to an error of 10.5 torr at 525 torr total pressure, which is very nearly equal to the 11.8 torr error that existed in the water output prior to adjustment of the buffer amplifier.

This error results from the action of the closed loop, which makes up for the erroneously high H₂O electrometer amplifier output by dropping the ionizing current to achieve the correct total pressure. Reduction of the H₂O buffer gain led to a low value for the summation of the partial pressures.

TABLE 3

Results of Calibration Verification During the 5-Day Test

	ERRORS, PERCENT			
	N ₂	O ₂	CO ₂	\sum pp
INITIAL	+0.23	+0.23	+0.47	+0.23
FINAL	-0.91	-0.71	-0.70	-0.84

During the 90-day test the Atmospheric Sensor performed without malfunction. Five calibration verifications were run during the course of the test and the data from these is presented in Table 4. This data shows that the mass spectrometer maintained its calibration within very close tolerances. The last adjustment of the instrument was made on 30 April, 1970. Therefore, the analyzer maintained its calibration on N₂, O₂, and CO₂ within 0.9, 2.1, and

2.7 percent, respectively, for a period of 132 days. The sum of the dry gas partial pressures remained within 0.84 percent during the same period. It is difficult to evaluate the performance of the instrument by any means other than the calibration verification data. Typical output data for the instrument is shown in Figures 11 through 13. This data was taken from the computer reduced data obtained on the MDAC Low Speed Data Acquisition System at 1800 hours on each day of the test. This time was selected because it was considered the most "normal", with the least unprogrammed activity, and should give a more representative picture of the cabin atmosphere from day to day.

Figure 11 shows the variations in the oxygen and nitrogen partial pressures; Figure 12, the variations in the carbon dioxide and water vapor partial pressures; and Figure 13, the variation the cabin pressure, the sum of the partial pressures, and the difference between these two values. A cursory review of the data has indicated that the fluctuations in the partial pressures are usually accounted for by specific known events that occurred within the SSS. The oxygen partial pressure was controlled within a total variation of 2.9 torr or better than ± 1 percent. The total pressure variations are much wider primarily because of a lower gain in the nitrogen make-up portion of the atmospheric control system. The variations in the carbon dioxide and water vapor partial pressures reflect changes in the status of the solid amine and molecular sieve CO₂ scrubber systems. The summation of the partial pressures is consistently low because of the incorrect summing resistor in the water channel, as predicted by the last data point taken during the 5-day test run. The indictment of the water channel is made even clearer by comparing the correlation between the water vapor output and the error in the summation of the partial pressures. Note that whenever the water vapor level goes up the summation of the partial pressures goes down, and vice versa. This is exactly what was expected from a detailed analysis which was made of the interchannel effects of an incorrectly established summing resistor.

TABLE 4

Results of Calibration Verification During the 90-Day Test

DATE	TIME	Error, percent			
		O ₂	N ₂	CO ₂	\sum_{pp}
6-13	1315	+1.1	+0.1	-1.5	+0.4
6-18	1902	+0.7	-0.4	0.0	0.0
7-8	1135	+0.9	-0.6	+0.8	0.0
7-13	1346	+1.3	-0.5	+0.6	0.0
9-9	0250	+2.1	-0.3	+2.7	+0.1

During the course of the 90-day test it was found that the CO₂ output of the mass spectrometer was not in agreement with the infrared analyzer. Consequently, on 21 August, 1970, a portion of the gas utilized to make the initial calibration of the mass spectrometer was sent to the laboratory that made the original mixture analysis. The results are shown in Table 5.

TABLE 5

Comparison of Calibration Gas Analyses

Component	Mixture 7130P	
	1/30/70	8/21/70
Nitrogen	66.166	66.336%
Oxygen	31.271	31.632%
Carbon Dioxide	2.544	2.012%

Note that the calibration for CO₂ changed by more than 20 percent. If the later calibration figures are utilized, the agreement with the infrared analyzer is very close. There is no reason to suspect that the calibration gas changed during this period, and therefore, it must be concluded that the original calibration was in error.

At the conclusion of the 90-day test the Atmospheric Sensor was shut down and returned to Perkin-Elmer Aerospace Division where it is now being operated on laboratory ambient atmosphere for a period of 180 days.

CONCLUSIONS

The Atmospheric Sensor was shown to be a reliable and accurate instrument for monitoring nitrogen, oxygen, carbon dioxide, and water vapor during the course of the 90-Day Manned SSS Test. It demonstrated its capability not only to monitor these constituents but to provide outputs that could be utilized by an atmospheric control system for regulation of the primary atmospheric constituents of a closed environment. The closed loop operating mode controlled the sensitivity of the mass spectrometer so that it could operate for a period of 132 days without a calibration. The accuracy of the outputs was affected by the initial calibration, which was found to be in error because of a faulty calibration technique in the case of water vapor, and an inaccurate calibration gas mixture in the instance of carbon dioxide. These procedural matters have been rectified and should allow the Atmospheric Sensor to perform to its full capability in future applications.

The 90-Day Manned SSS Test was intended to prove out equipment for application to future space stations. It is therefore important to assess the feasibility of reducing the size, weight, and power of the Atmospheric Analyzer to levels which are compatible with a flight program. A contract under the direction of NASA Manned Spacecraft Center is currently in progress for the development of a flight qualified Mass Spectrometer Atmospheric Sensor System (MASS) as well as a modified version to be used as a respiratory gas analyzer as part of the M-171 Metabolic Analyzer, which will be used in Skylab in 1972. A photograph of the instrument is shown in Figure 14.

These units are fully self-contained and require only a sample inlet and bypass line, a small diameter vacuum line to outer space for initial roughing of the mass spectrometer, system power, and command functions for the ion pump mass spectrometer electronics, open-loop/closed-loop control, and selection of one of the dual ion source filaments. The system is fully protected against operation at excessive pressures and provides status indicator outputs on all important functions that can change during operation. The inputs and outputs are fully isolated and protected and the instrument has sample inlet heaters and ion source temperature control for improved performance.

The design is fully compatible with Apollo and Skylab environments including a 38 lbf/in² abs over pressure requirement. The atmospheric monitoring version of this instrument measure the partial pressures of hydrogen, water vapor, nitrogen, oxygen, carbon dioxide, and hydrocarbons in the mass range 50 to 120 amu. The final configuration of this system weighs 21 pounds, requires 19 watts of power during normal operation, and has a cylindrical enclosure with a diameter of 7.2 inches and a length of 12.5 inches. The first design verification test unit of the MASS is scheduled for delivery to NASA MSC in November 1970.

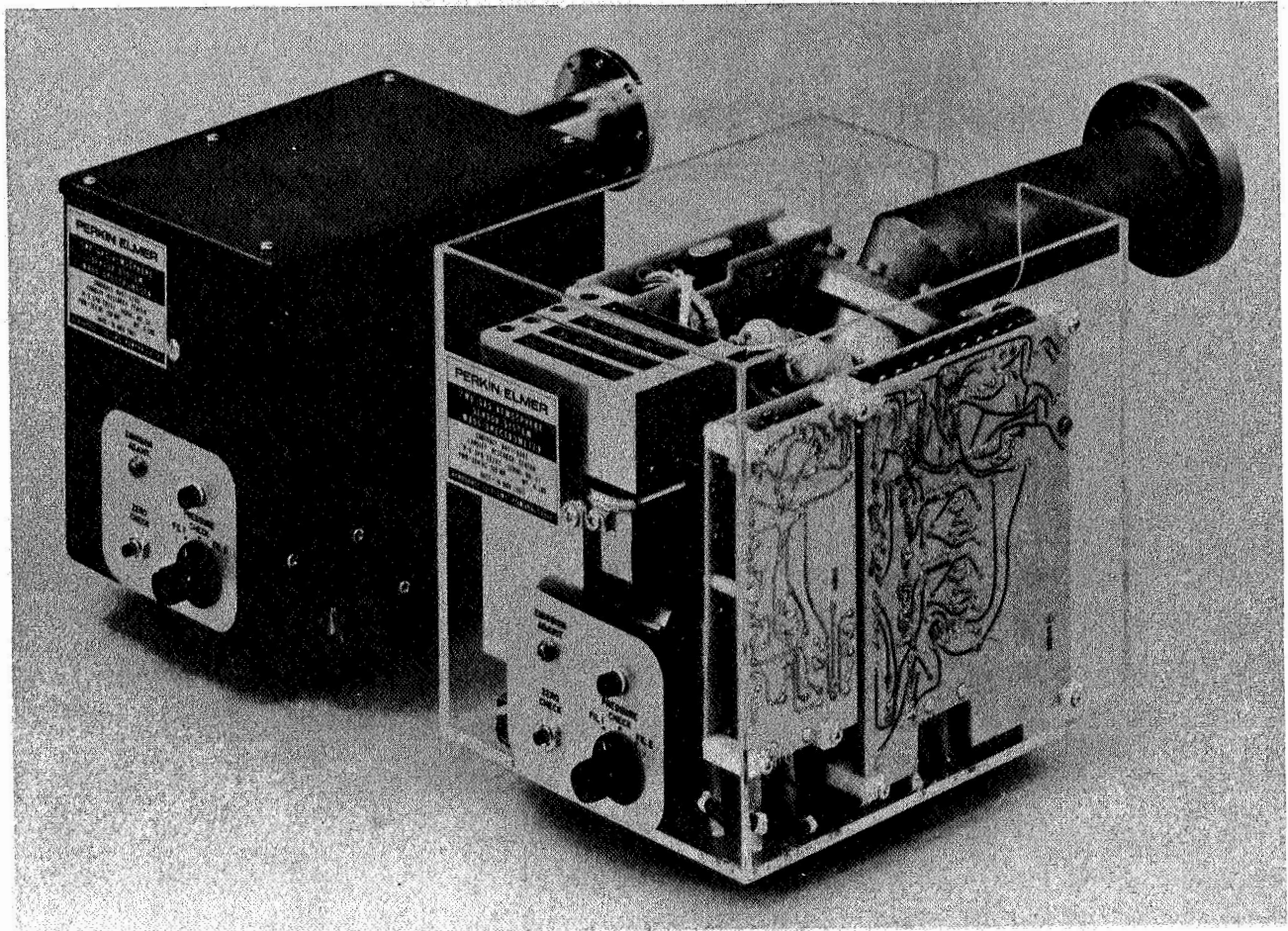


Figure 1.- Two gas atmosphere sensor system.

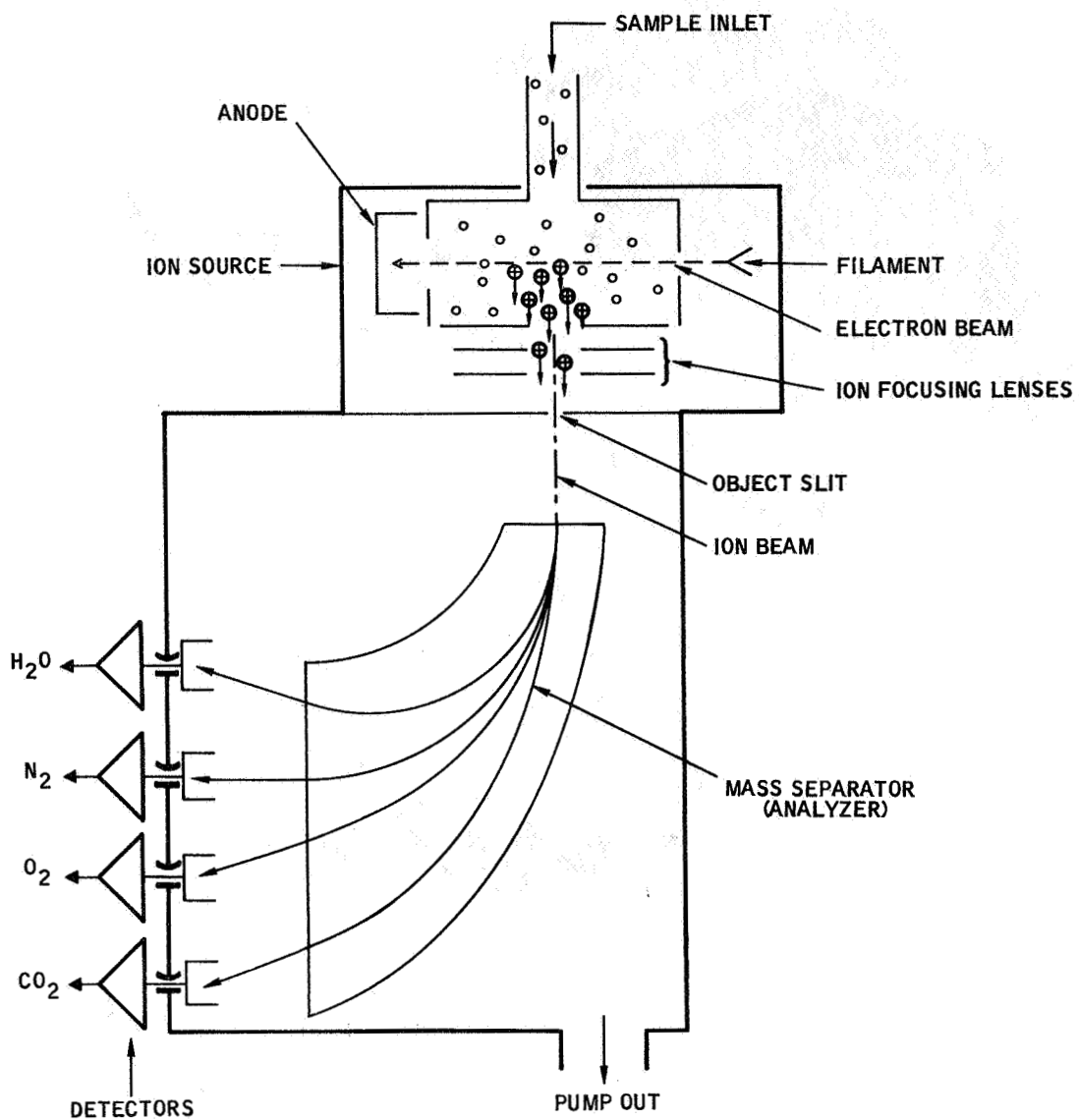


Figure 2.- Principles of mass spectrometer operation.

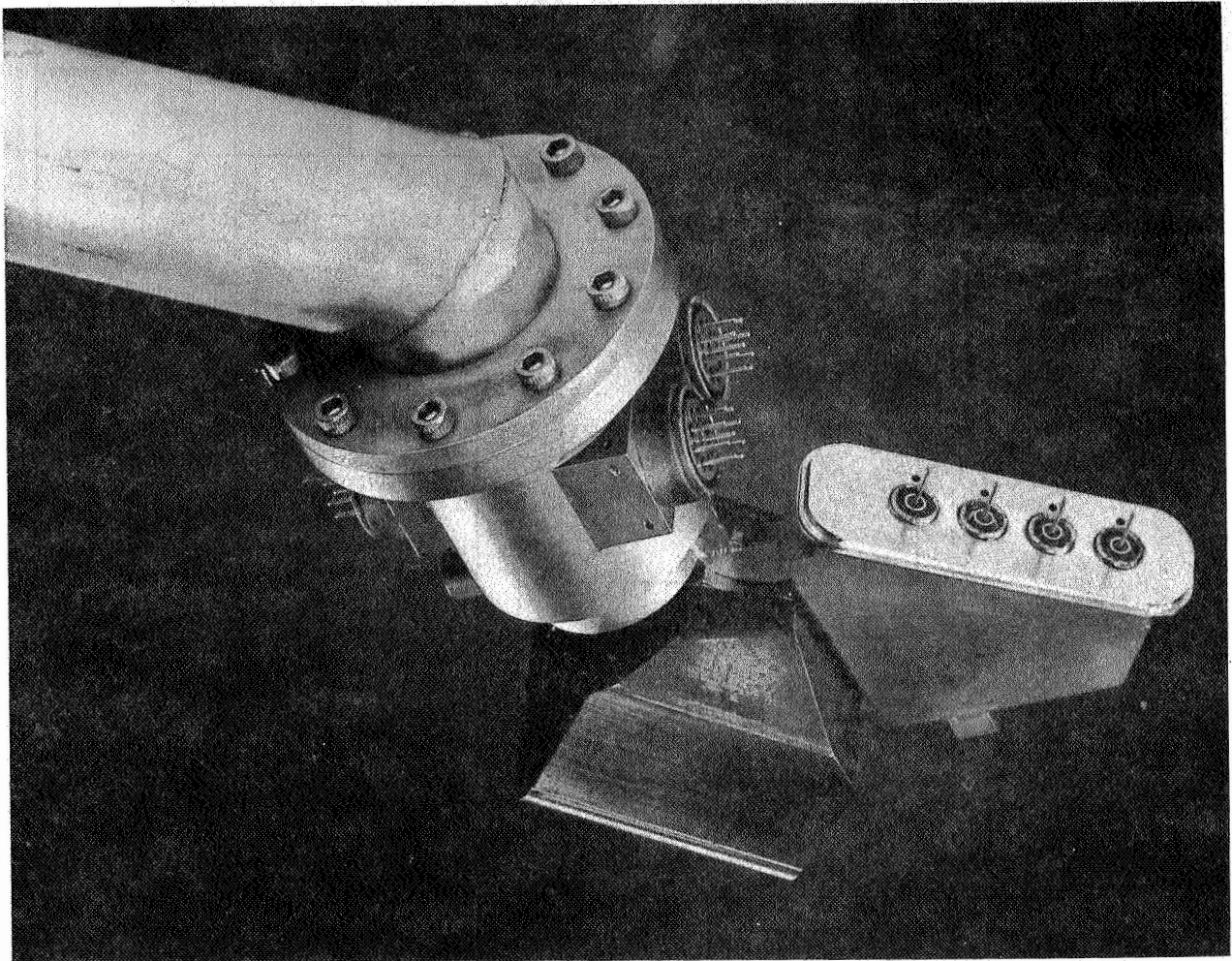
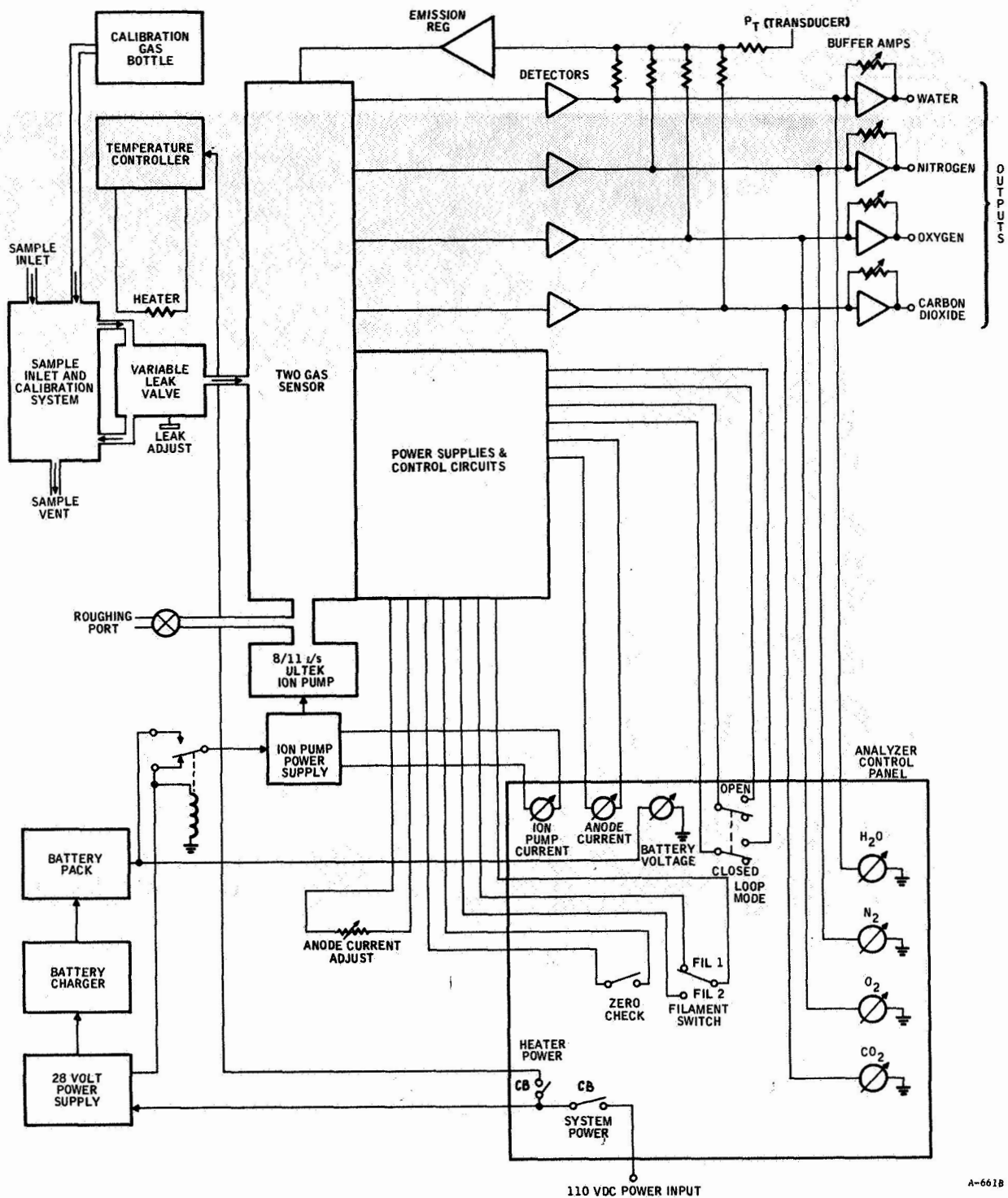


Figure 3.- Two gas sensor mass spectrometer analyzer assembly.



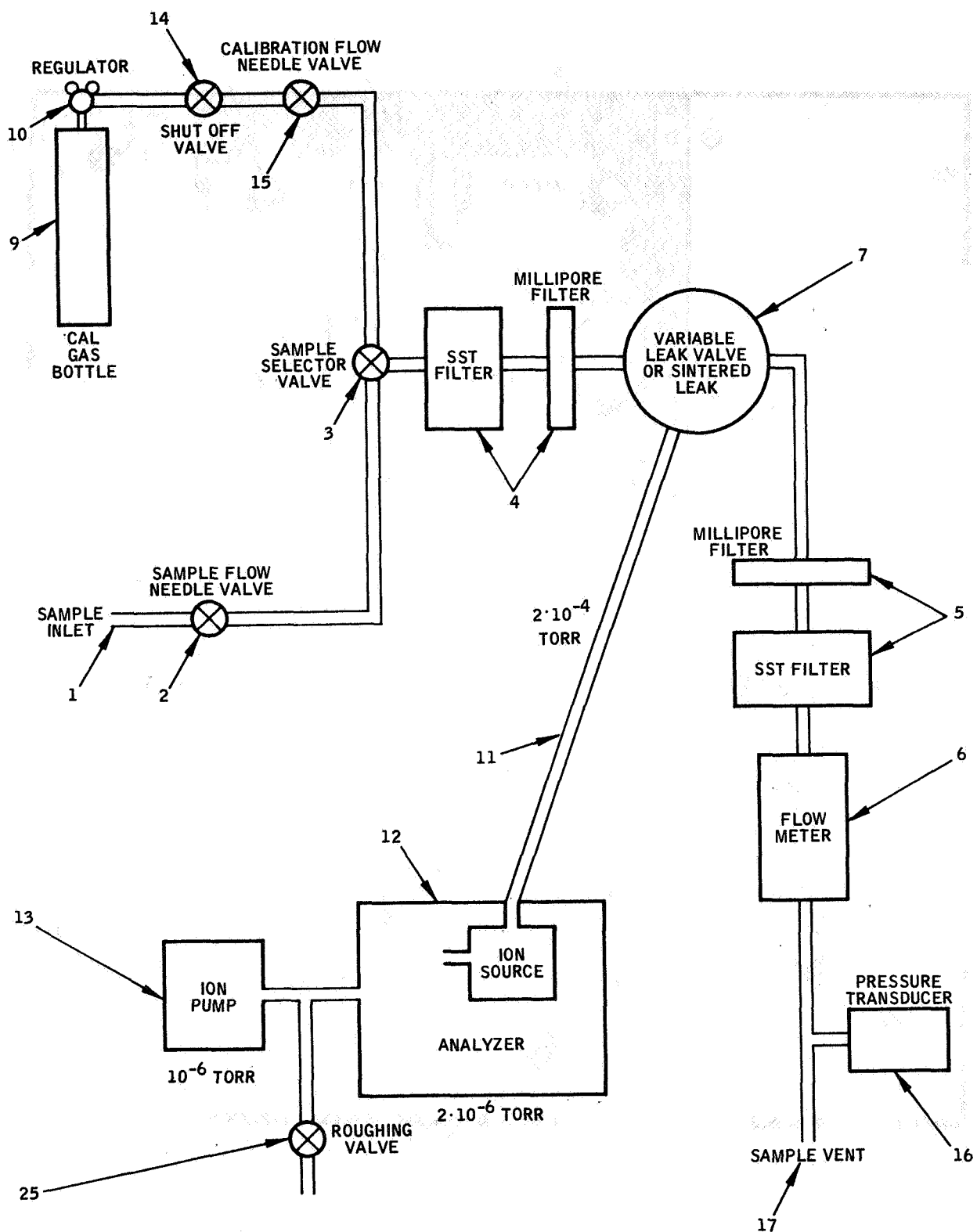


Figure 5.- Sample and calibration inlet system schematic flow diagram.

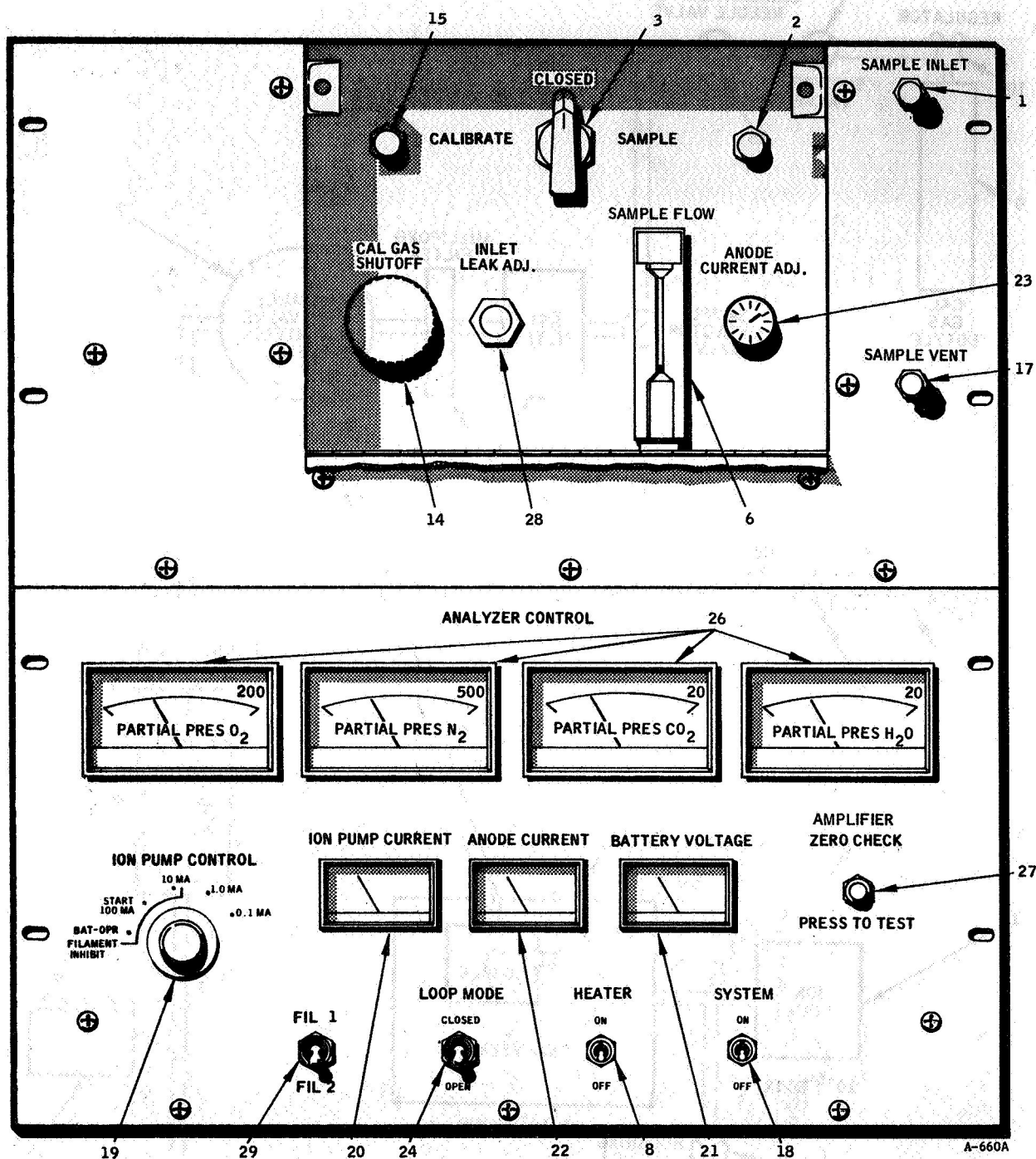


Figure 6.- Atmospheric sensor front panel.

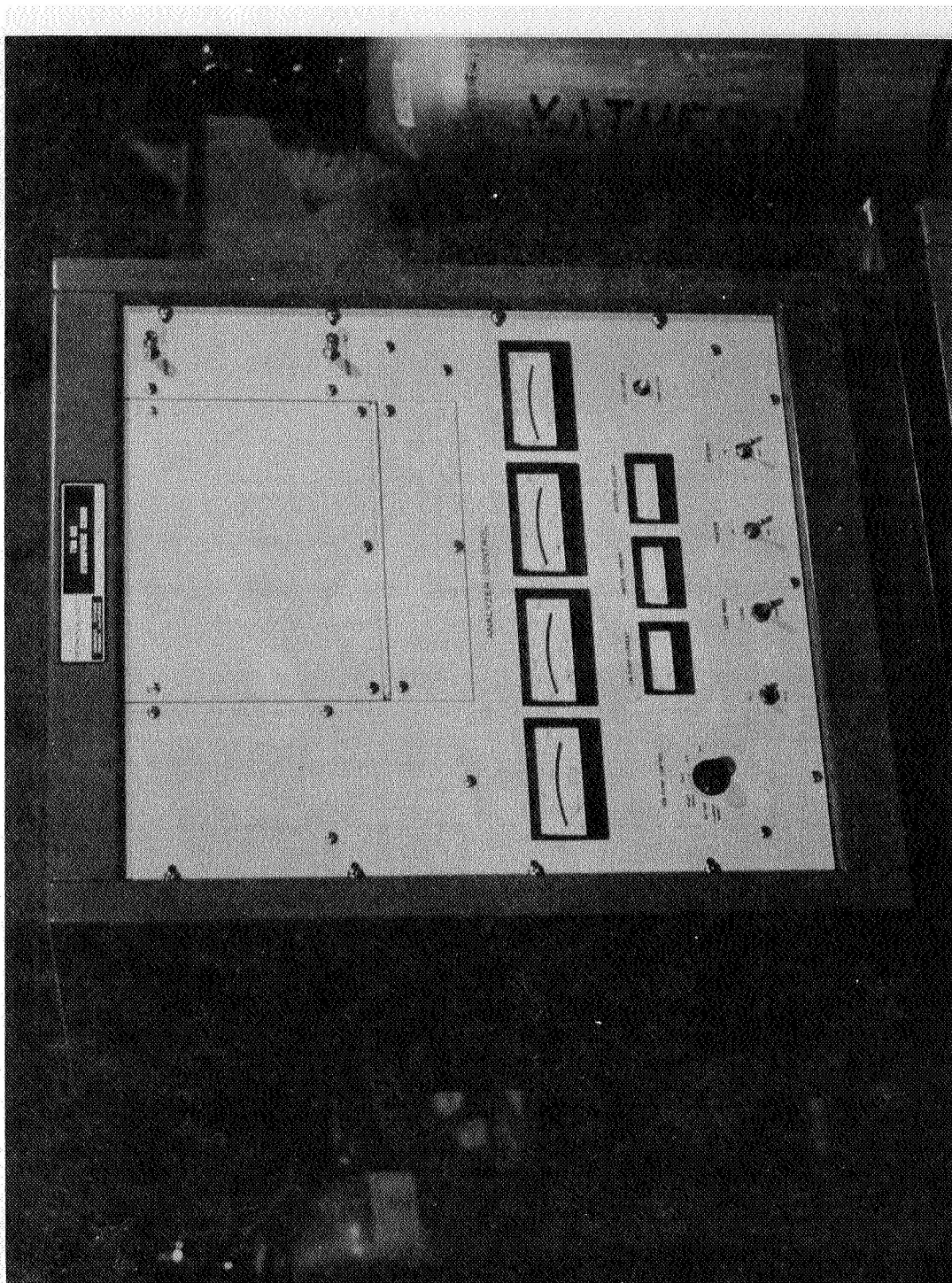


Figure 7.- 90-day space station simulator atmospheric sensor system.

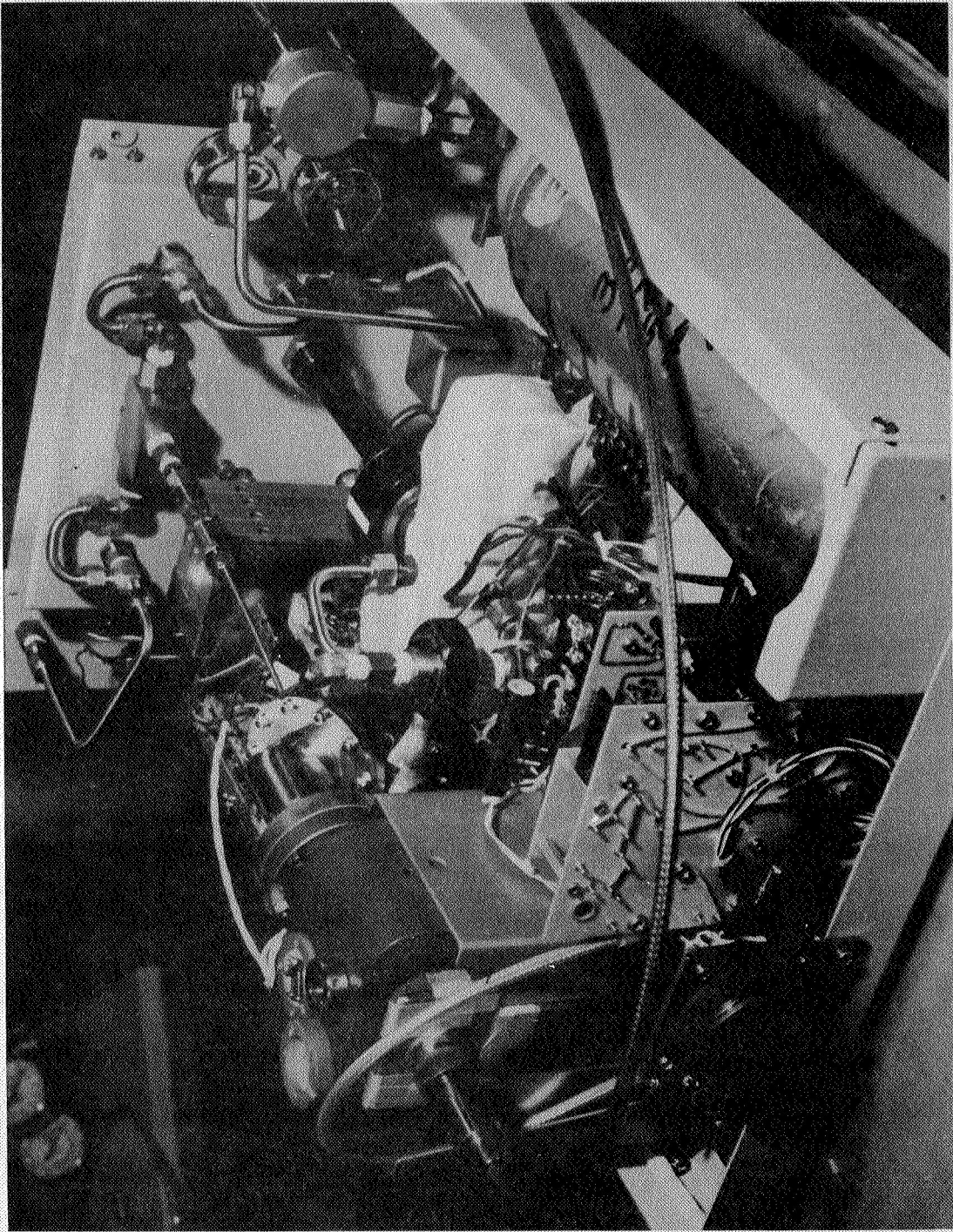


Figure 8.- Atmospheric sensor – upper bay.

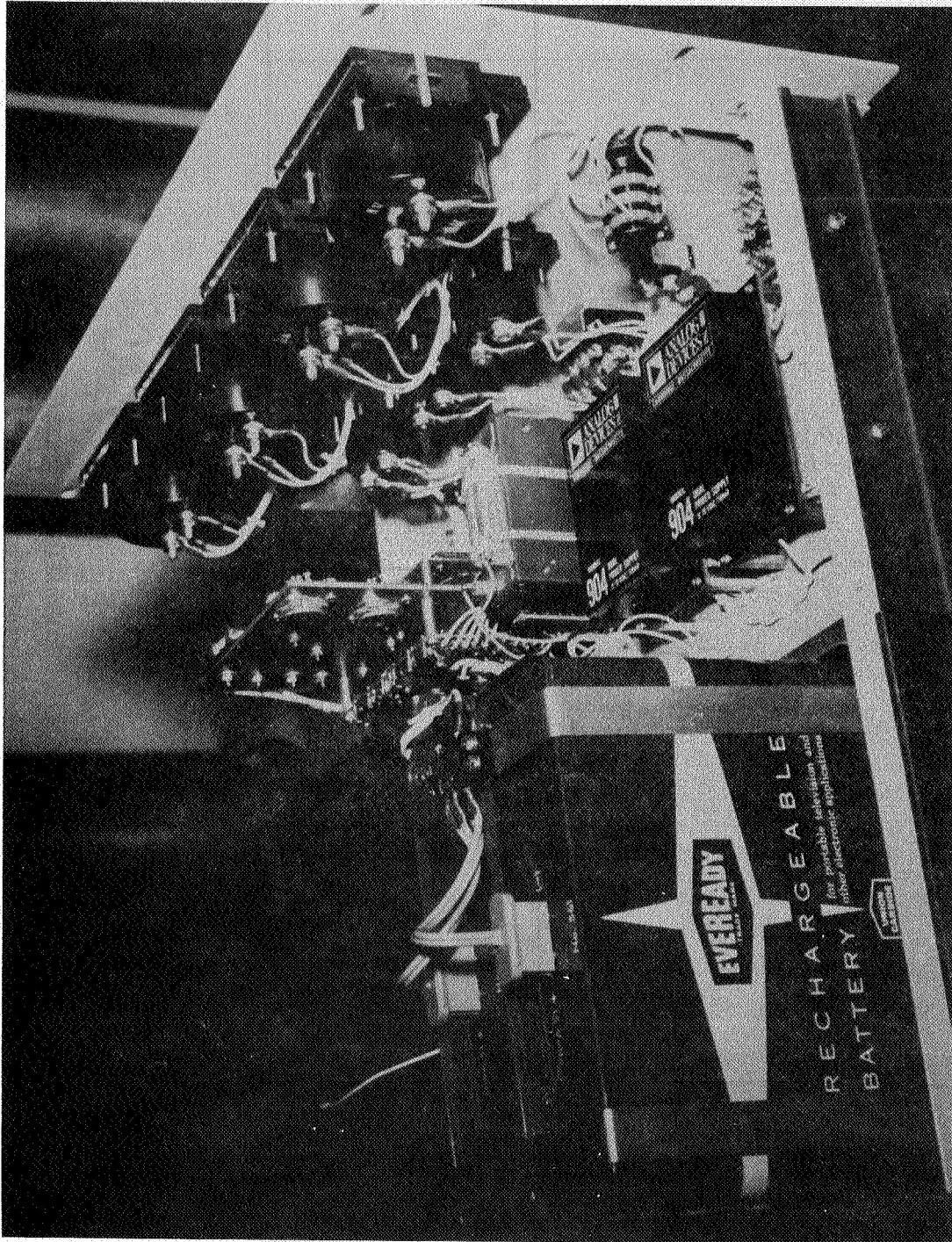


Figure 9.- Atmospheric sensor - lower bay.

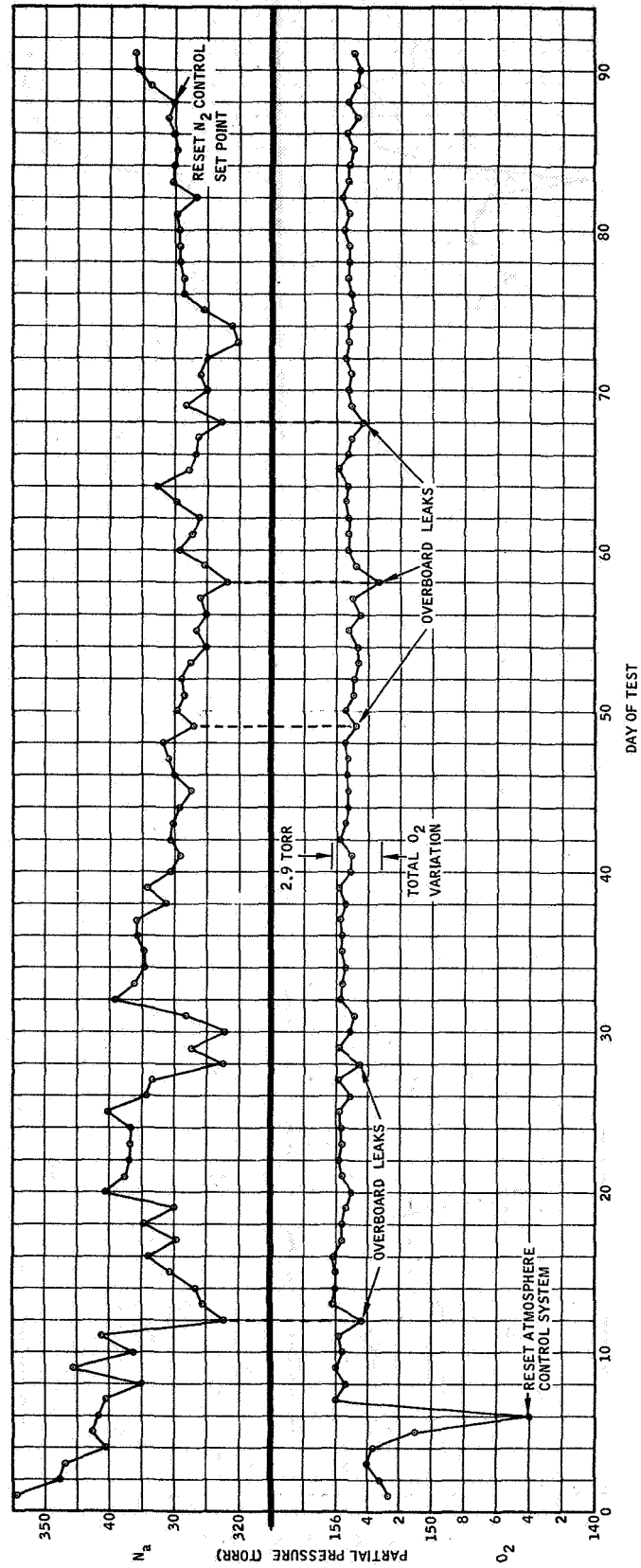


Figure 11.- Oxygen and nitrogen partial pressures during the 90-day test.

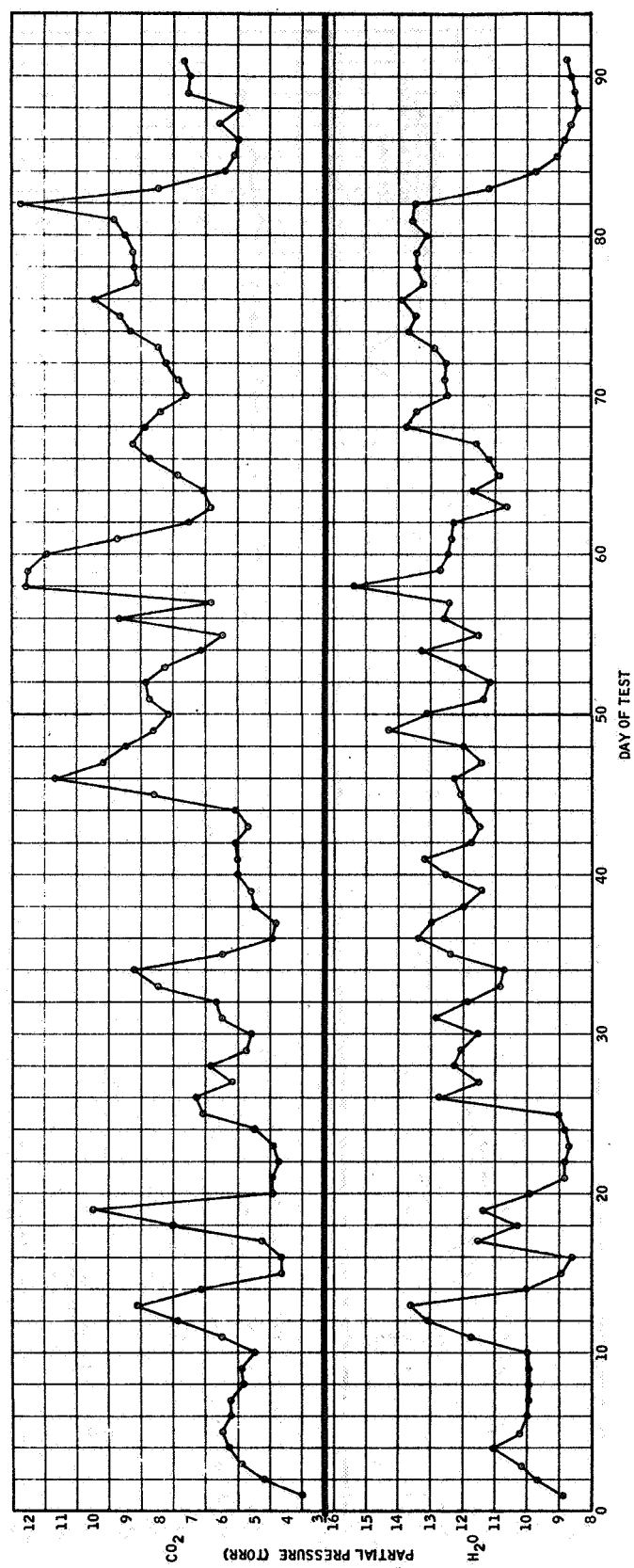


Figure 12.- Carbon dioxide and water vapor partial pressures during the 90-day test.

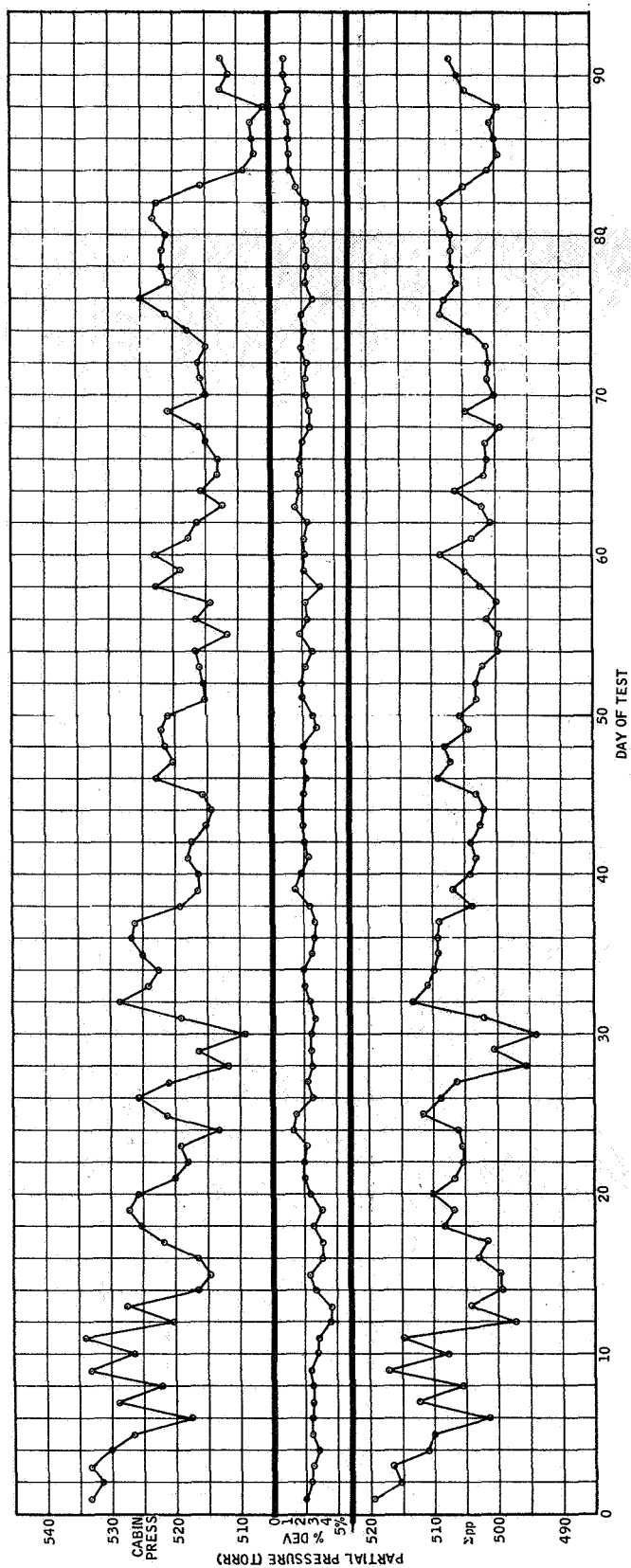


Figure 13.- Comparison of the summation of partial pressures to the total pressure during the 90-day test.

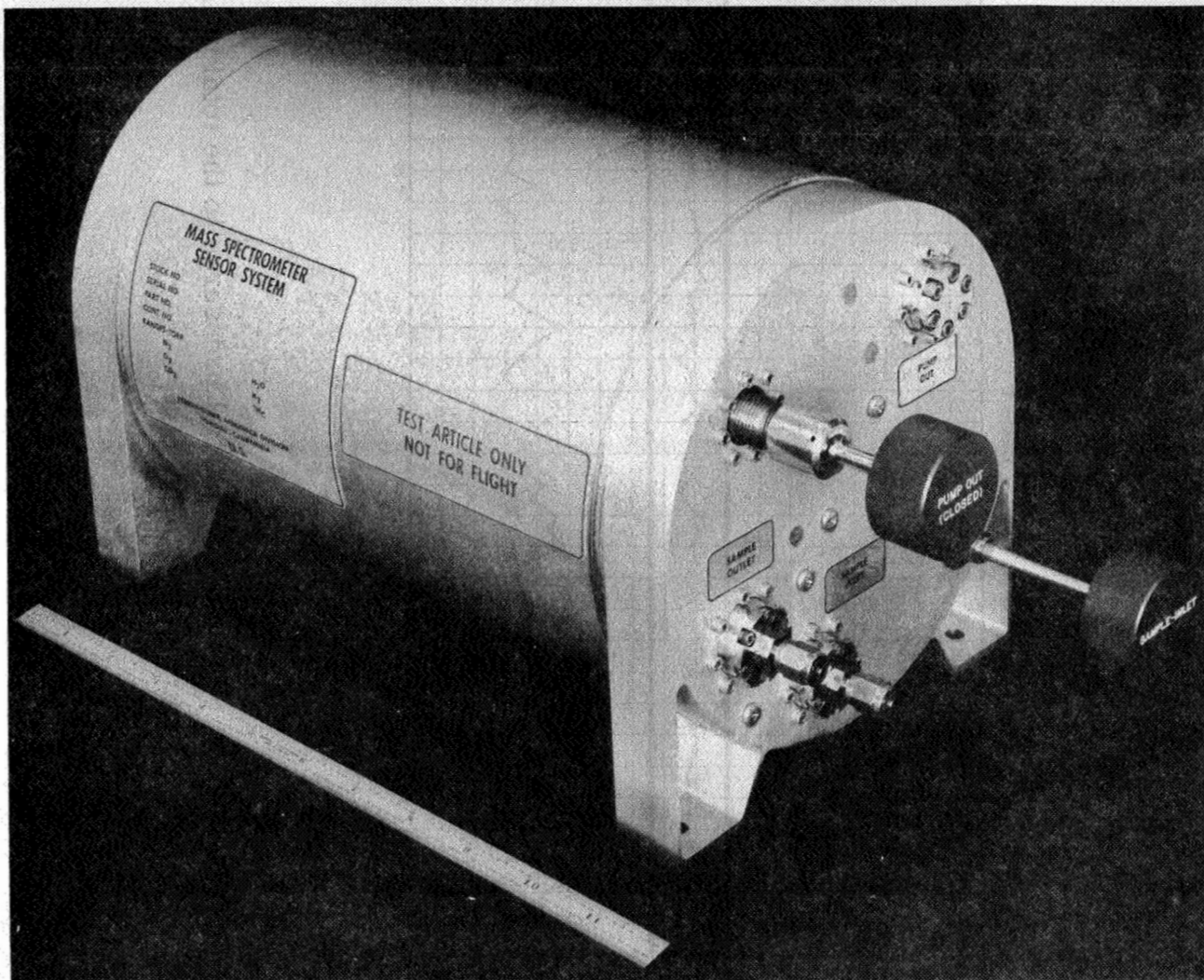


Figure 14.- Flight qualified mass spectrometer atmospheric sensor system for atmospheric and respiratory monitoring.

DESIGN AND OPERATION OF A WASTE MANAGEMENT SYSTEM FOR
FECAL COLLECTION AND SAMPLING DURING THE 90-DAY

MANNED SIMULATOR TEST

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SUMMARY

A component designed for the collection, processing, and storage of feces and toilet tissue aboard aerospace vehicles has been fabricated and successfully tested. This system is a type similar to the "Dry John;" however, this new design extends the useful life of the prior design by use of a replaceable liner assembly (liner, slinger, motor, and filter), sized for approximately 200 man-days accumulation. The filter prevents contamination of all downstream lines and permits changing of the liner without contamination of the cabin. Other features of the unit are a quick-acting slide-valve assembly, a fecal sampler, and a disinfectant dispenser.

INTRODUCTION

Various means of collecting and processing feces and other solid wastes in zero-gravity environment aboard spacecraft are being investigated in a number of programs. Several of these have been supported by the Aerospace Medical Research Laboratory, both in-house and on contract. One such program was for the development of a four-man, 60-day waste management system (ref. 1), which was used in a simulated space chamber (ref. 2). This system called "Dry John" in turn was used as a base-line for an improved version, called Extended Life Dry John (ELDJ), which was used in a recently completed four-man, 90-day test sponsored by NASA and conducted by McDonnell Douglas Astronautics Company (MDAC). This report describes the components and operation of the system. Results obtained during the 90-day test are presented by MDAC in paper no. 19 of this symposium.

SYSTEM DESCRIPTION

A photograph of the system is shown in figure 1. The individual components of the system are identified in the system block diagram of figure 2. These components are a seat to support the user, a slinger-shredder to spread feces on the liner where they can be quickly vacuum dried, a unit for dispensing disinfectant onto the feces for odor and bacteria control, and a removable liner which extends the useful life of the system. Items not part of ELDJ, but

necessary for it to function, are a blower to provide fecal transport and odor control, a vacuum system to dry accumulated feces, an odor filter, a secondary bacteria filter, a power source (400 Hz, 3-phase, 115/200 volt), and a quick disconnect.

SYSTEM OPERATION

The first step in the operation of the ELDJ is to open the seal valve under the seat. This action, by means of interlocking solenoids, starts the slinger and blower, opens the blower line from the system, and closes the vacuum line from the system. Cabin air is immediately drawn into the container, thus preventing backflow of odor, bacteria, or debris from the container to the cabin. The user then occupies the seat, which is contoured according to guidelines in reference 3. This seat contour provides comfortable support to the user as well as a means of indexing himself over the storage container. Upon defecation, the stool is transported by gravity and airflow (in zero gravity, air is the only means of transport) to the flat surface of the slinger. Here the stool is slung outward and shred by the slinger tines then spread on the interior surface of the storage container liner. Each layer of feces spread in this manner is densely packed and sufficiently thin to be dried rapidly by the subsequently applied vacuum. Used toilet tissue is dispensed with in the same manner as feces; however, the tissue will not shred if it is dry. After tissue disposal, a predetermined quantity of disinfectant is injected onto the slinger by pressing the disinfect switch. The slinger then sprays the disinfectant over the spread feces. Any dry tissue that might have become entangled on the slinger tines will be wet by the disinfectant and then dislodged from the tines; hence, the disinfectant provides a secondary benefit of helping to clear the slinger tines in addition to the primary one of reducing bacteria and odor. The blower which is run during usage for fecal transport also helps to control odor and bacteria by drawing gases associated with defecation through a filter before these gases can diffuse into the simulator environment. When finished, the user closes the seal valve under the seat. This action, the reverse of the first step, stops the slinger and blower, closes off the system from the blower, and opens the system for vacuum drying of the contents.

If a fecal sample is needed, a cap covering the sample port is removed and the fecal sampler (see fig. 3) is inserted into the ELDJ before usage. This action of inserting the sampler opens the sampler cavity in which feces are collected as they are slung toward the liner. Conversely, the action of removing the sampler closes the sampler cavity in which the feces sample has been collected. The sampler, as it is being removed from the ELDJ, is drawn into a plastic bag which is then sealed. This bag is fitted with a valve to permit gas sampling or vacuum drying of the contents, if required. After sampler removal, the cap is replaced on the sampler port.

The ELDJ components for collecting feces, distributing them with a slinger-shredder, and providing airflow for odor and bacteria control and for transport of feces, are similar to corresponding Dry John hardware. However, to extend the useful life of the present unit compared with that of the Dry John, the

present unit is provided with a replaceable liner sized for approximately 200 man-days of usage, hence the name Extended Life Dry John, or ELDJ.

To allow convenient installation or removal of the liner, a split container is used. A single quick-acting V-band clamp joins and seals the two container halves. Likewise, other quick disassembly devices are used at all "break points." When the liner is removed and discarded, the slinger and filter are also removed and discarded because they will have been subjected to fecal contamination. The motor will also be discarded because the cost and weight of additional components which would be required for salvage approximate those of the motor itself.

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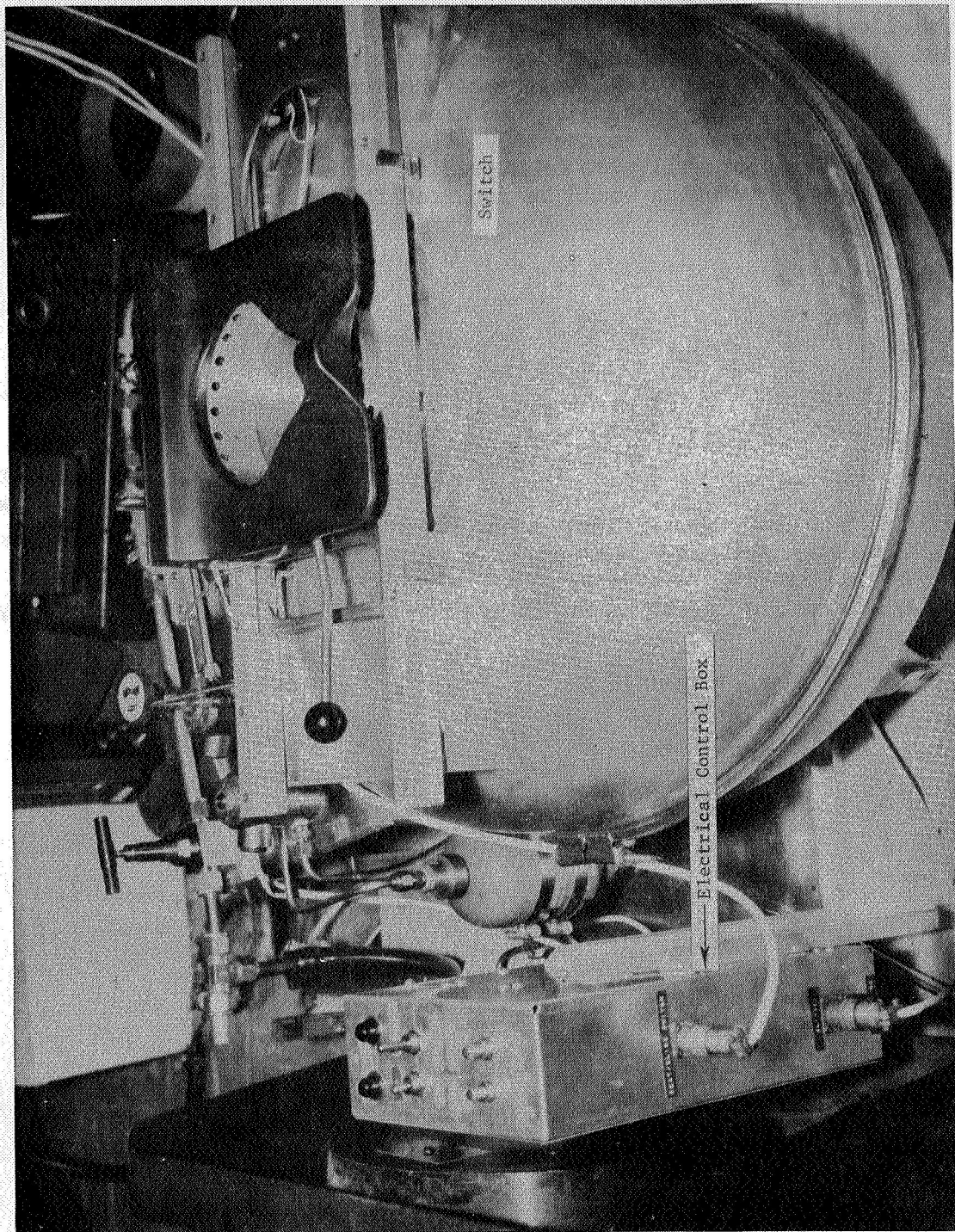


Figure 1.- Waste management system (commode).

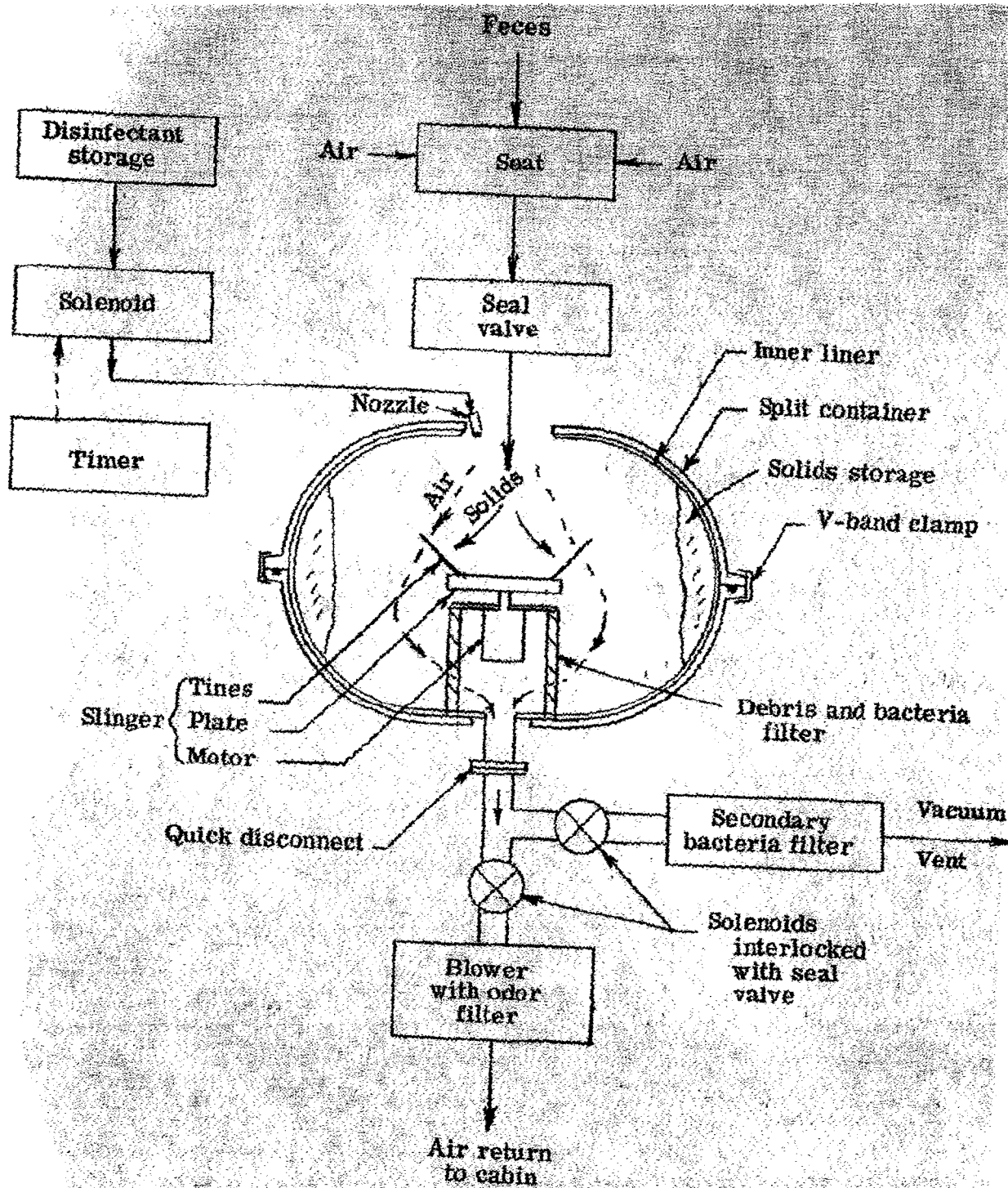


Figure 2.- System block diagram.

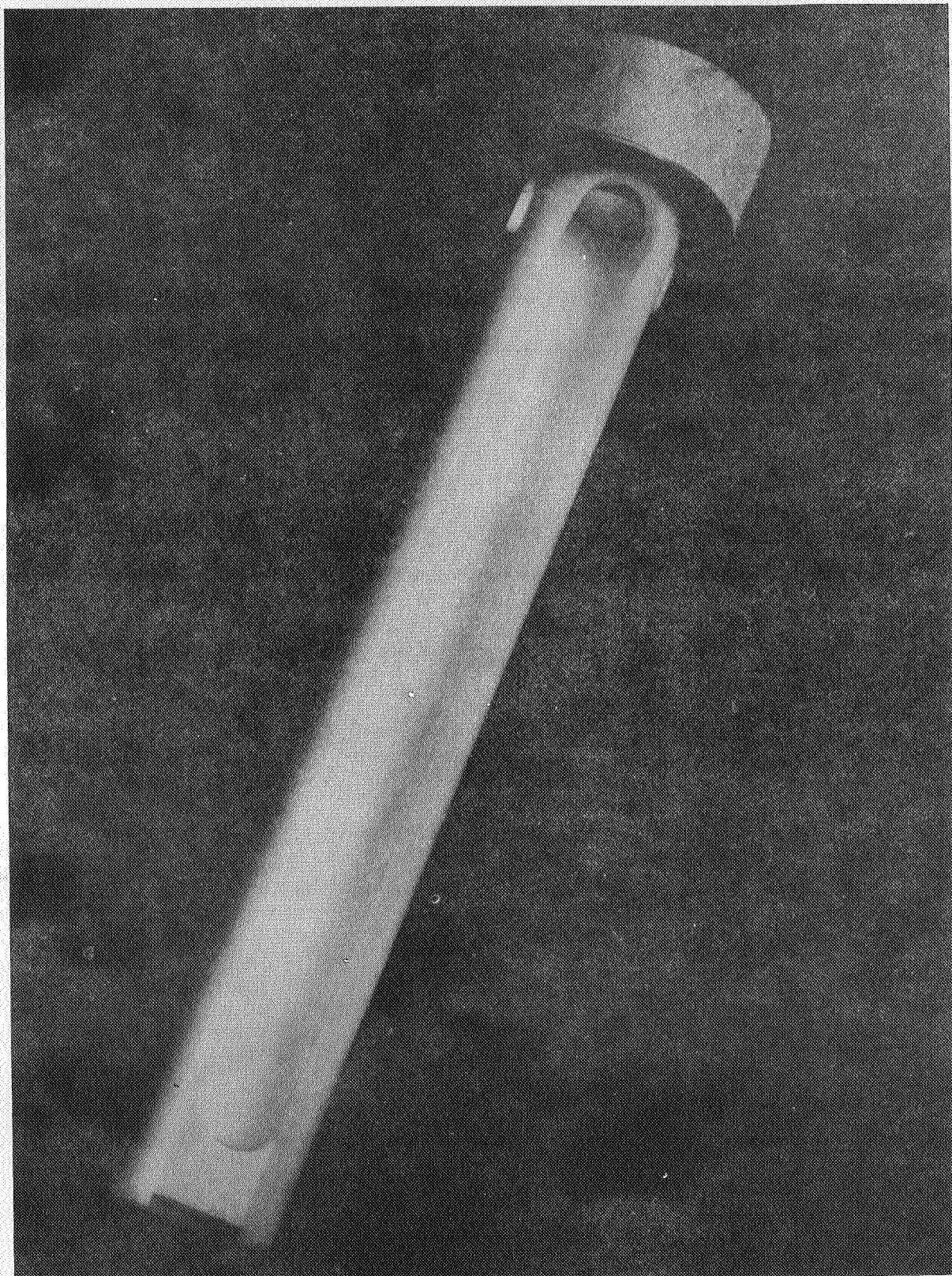


Figure 3.- Fecal sampler.

WASTE MANAGEMENT SUBSYSTEM

By J. K. Jackson and R. E. Shook

McDonnell Douglas Astronautics Company

SUMMARY

The waste management subsystem included the commode, urine collector, and urine phase separator. The commode was provided by the Air Force Aerospace Medical Research Laboratory (AMRL) and manufactured by General Electric. The urine collector was an Apollo type with built-in flush water injector, provided by NASA-MSC. The urine phase separator was built by MDAC for this program, and included automatic pretreatment injection. Operation and crew acceptance of all units were generally adequate except the urine phase separator, in which the polyurethane impeller was dissolved early in the test by an accidental injection of concentrated pretreatment solution. Subsequent use of the urine collection system required the use of gravitational forces for phase separation. The commode required liner replacement once during the mission, on day 44, and was used 319 times.

INTRODUCTION

The design guidelines for waste management during the 90-day test included: minimum crew handling of waste products following elimination, effective control of odors and bacterial contamination to the cabin, convenience of operation and maintenance, and design for zero-gravity operation. A "Dry John" commode which had been built for AMRL by General Electric had been previously used by MDAC in the 60-day test. This unit included a slinger-type collector with air induction of feces, a spherical bowl for storage, and sequencing valves for vacuum dehydration between uses. This unit had performed satisfactorily according to the above guidelines, but was expected to have inadequate capacity for the 90-day test resulting from the increased duration and the predicted increase in residual fecal solids because of the improved diet. An improved model was therefore built which included a replaceable liner in the collector bowl, a sampling device, improved controls and valves, and a disinfectant injection system.

During the previous 60-day test, urine pretreatment solution had been inaccurately added. A urine collection unit was therefore built by MDAC to provide automatic addition and to adhere to the requirement for null-gravity capability.

EQUIPMENT DESCRIPTION

The waste management system is shown schematically in figure 1. A description of the commode and associated equipment is included in paper

number 18 of this symposium. In addition to this equipment, a toilet paper collection receptacle was provided as a contingency in the event adequate collection capacity was not available in the commode. This was connected to the vacuum system in parallel with the commode and used a porous paper bag such as is used for a disposable vacuum cleaner collector. When filled, these bags were sealed and placed in the dry waste storage container.

The urine collector operated on an air entrainment principle, similar to the fecal collector. A centrifugal separator, using a porous polyurethane impeller, was used to separate the air from the urine. The air then passed through a charcoal filter for odor adsorption and was returned to the cabin by a small blower. Pretreatment fluid, which was a solution of sulfuric acid, chromic oxide, and copper sulfate, was stored in a reservoir and proportionally added to the urine stream. The urinal was located adjacent to the fecal collector and could be used separately or in conjunction with the commode. An Apollo type urine collector with provisions for flush water injection was provided by NASA-MSD.

Several methods were provided for handling of waste and garbage. Excess water remaining from preparation of some food items was added to other highly contaminated water including concentrated sodium hydroxide solution from the microbial sensor and periodically pumped overboard. Wet garbage was sealed in standard No. 2 metal cans after treatment with 8-hydroxy quinoline sulfate for bacterial control. The disposable dishes were stored in aluminum boxes having tight-fitting covers after being similarly treated with bactericide. Food packaging material was baled and wrapped with aluminum foil, in which the meal packs were originally wrapped, and stored in cabinets. A large aluminum container was provided for other dry waste, including filled toilet paper bags. This container was fitted with a sealing cover about 12 in. in diameter and could be vented to the SSS annulus periodically if desired to remove odors.

TEST RESULTS

The commode operated very satisfactorily during the 90-day test. Table 1 presents comments on commode operation. Table 2 is a summary of commode performance. During use of the first liner, all toilet paper was put into the commode. The liner was considered full and was changed on day 44, at which time it appeared to be about two-thirds full. The used liner was stored in the unused pass-through airlock for the balance of the mission. During use of the second liner, the crew was instructed to place used toilet paper in a separate receptacle. At the end of the test, the liner appeared to be about one-third full. Separate collection of toilet paper appears to be desirable for extension of liner life.

One significant operational error occurred. On day 38 one of the crewmen noticed the Wescodyne disinfectant was not being injected into the commode after use. Subsequent checks revealed that a nitrogen valve controlling pressure to the disinfectant tank had been closed since the start of the test. Subsequent injection was satisfactory. The tank was refilled once during the run.

The urine collection system operated until test day 6 when the time-delay relay controlling pretreatment addition remained energized, allowing a large quantity of pretreatment solution (sulfuric acid, chromic oxide, and copper sulfate) to enter the phase separator. This dissolved the polyurethane foam impeller. Subsequent to this, urine was collected in a beaker and measured, and pretreatment solution was manually added. Until day 41, this urine was poured directly into the urine accumulator. At this time, the test crew installed a direct line from the urinal to the urine accumulator to allow a direct transfer. Subsequently, the urine was poured into the urinal and flush water was then manually added. Pretreatment was added in 15 ml amounts as required by urine output. Antifoaming agent was added at the urine accumulator when the VD-VF system was operating.

The wet waste was stored in 42 No. 2 cans. The test crew was instructed to pass cans out of the chamber on the regular weekly pass-out if there were signs of bulging or indications of potential rupture. As a result, 23 of the filled cans were passed out during the test. Saving these at room environment resulted in only 5 developing discernable bulges. One of these was opened and found to contain a high concentration of potassium hydroxide, apparently included in a wiping cloth, and much resulting corrosion. Contents of other cans have not yet been examined. However, it appears that the crew was improperly instructed in material to put into the cans, and possibly overly cautious in passing them out. It was felt that, under no circumstances, should a chance be taken of a can rupture inside the SSS during the test.

Used food trays were stored in five of the aluminum boxes provided. A total of 2,408 trays were used, with a maximum number of 521 in one of the boxes. No problems were encountered with this disposal method.

Dry garbage stored in the big container weighed 17.65 lb, including four bags of toilet paper having a total weight of about 3 lb. A fifth toilet paper bag was in the receptacle next to the commode, nearly full.

No record is available of the amount of stored food wrappings, although no problems were encountered with their storage. Reuse of the original aluminum foil provided convenient, satisfactory, and safe overwrap for packages of used food wrappings.

MAINTENANCE SUMMARY

Table 3 summarizes the major maintenance items on the waste management subsystem. Most of the repairs required on the commode and urine collector have already been discussed. The leakage of the trash container caused some concern because a permanent correction could not be made. As a result, venting of the can to the annulus was done only occasionally when a noticeable odor was generated in the can. On one or two instances, significant loss of cabin atmosphere occurred when the can was left venting to the annulus. This was detected by the resulting loss in cabin pressure and corrective action was taken within a few hours to close the vent valve.

CONCLUSIONS

Design of the commode unit was generally satisfactory. It performed well and was accepted by the crew.

Problems encountered with the urine collector emphasize that a device handling a dilute solution of a very corrosive fluid must also be qualified to survive failure modes in which much more concentrated solutions are improperly introduced.

Handling of garbage and other general waste products requires further study. Perhaps the data on types and quantities produced will serve as a basis for system design to reduce the quantities and provide more effective means for handling them.

Table 1

COMMENTS ON COMMODE OPERATION

- Three of Four Adapted Readily to Seat Configuration
 - Induction Airstream Had Undesirable Drying Effect
 - Some Occasional Odor Was Noticed In Equipment Room Near Exhaust During Use
 - Odor Control Adsorbent was Approximately 3/4 Expended
 - Fecal Sampler Cap Was Considered Difficult to Insert
- Larger Handle Desired
- Could Not Check Adequacy of Seal
- Crew Anticipated Difficulties in Accomplishing Liner Change
- Actual Change Required 3 Hours 35 Minutes
- No Leakage Achieved On First Trial Assembly
- Fecal Material Does Not Stick To Liner--Dries In Chunks
 - Slinger Threw Dried Chunks Around Inside Of Collector
 - Liner #1, Including Toilet Paper, About 2/3 Full; > 90 Percent Paper By Volume
 - Liner #2, Without Toilet Paper, About 1/3 Full; < 10 Percent Paper By Volume

Table 2
COMMODE USAGE SUMMARY

	<u>Liner #1</u>	<u>Liner #2</u>	<u>Total Test</u>
Days Used	1 Through 43	44 Through 91	-----
Uses	142	177	319
Gross Solids Collect, lb	14.68	15.25	29.93
Toilet Paper, lb	3.08	0.25*	3.33
Net Fecal Solids, lb	11.60	15.00	26.6
Fecal Water, From Freeze Traps, lb	19.8	32.4	52.2
Total Feces	31.4	47.4	78.8
Fraction Water	.63	.68	.66
Average Uses Per Day	3.0	3.8	3.6
Maximum Uses Per Day	-----	-----	7
Minimum Uses Per Day	-----	-----	0
Average lb/Use	.22	.26	.25
Average lb/Day	.73	.97	.88

*Balance of the toilet paper was separately collected.

TABLE 3

SIGNIFICANT MAINTENANCE ON WASTE MANAGEMENT SUBSYSTEM

Unit	Maintenance activity	Spares usage	No. of Times	Hours
Commode	Corrected vacuum leak		1	0.2
	Corrected low N ₂ pressure on disinfectant tank		1	0.5
	Refilled disinfectant tank*	Wescodyne	1	0.5
	Replaced expended liner assembly*	Liner assy and seals	1	5.0
			<u>4</u>	<u>6.2</u>
Urine collector	Attempted modifications for one-g operation	Misc. fluid fittings, tubing and RTV sealant	3	10.0
	Corrected time delay control malfunction	Relay	2	0.3
	Modified urine pump installation	Misc. fluid fittings and tubing	1	0.5
	Modified to connect urinal to accumulator	Misc. fluid fittings and tubing	1	0.5
	Modified to install timer for urine pump control	Timer and misc. elect. items	1	3.0
			<u>8</u>	<u>14.3</u>
Trash container	Corrected vacuum leak to annulus	Vacuum grease	2	0.3
			<u>2</u>	<u>0.3</u>
		SUBSYSTEM TOTAL	12	20.8
		*PLANNED MAINTENANCE	2	5.5
			<u>10</u>	<u>15.3</u>
		UNSCHEDULED MAINTENANCE		

WASTE MANAGEMENT SUBSYSTEM

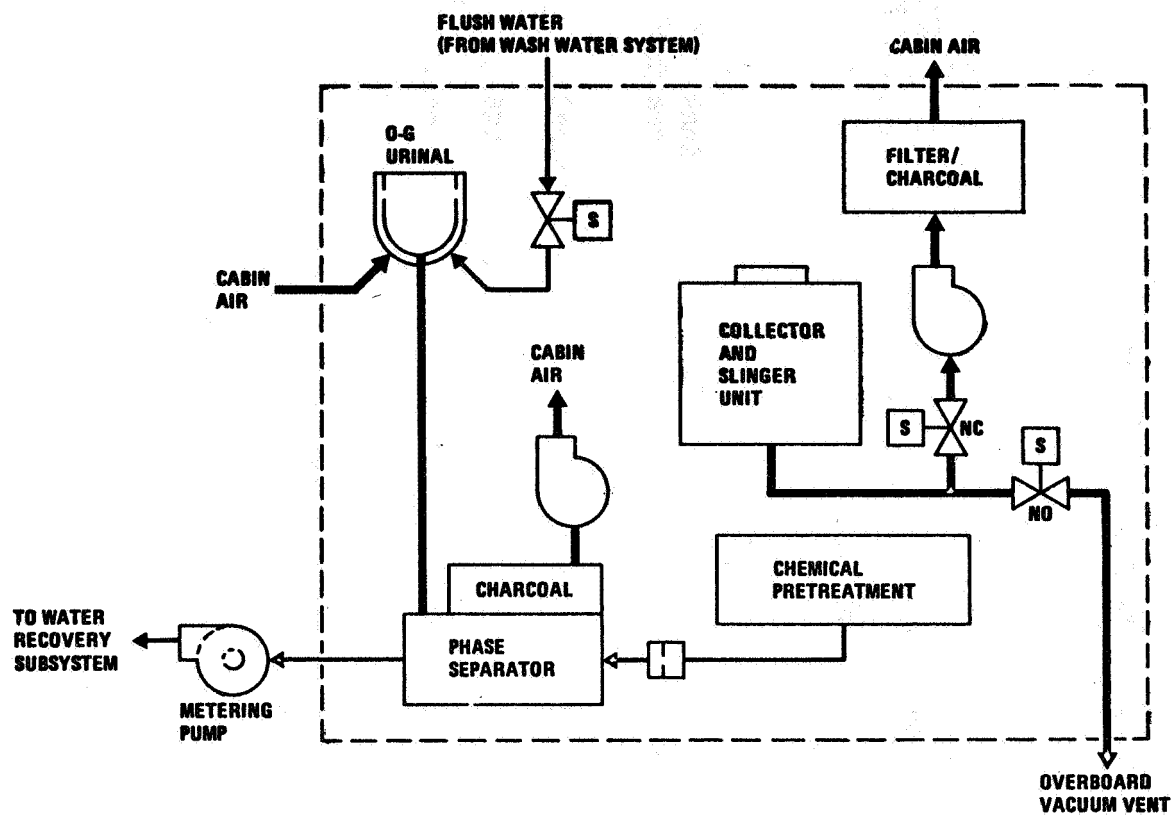


Figure 1

FOOD MANAGEMENT PROGRAM

By J. S. Seeman and D. J. Myers
McDonnell Douglas Astronautics Company

SUMMARY

The food provisions available to onboard crewmen during the 90-day test consisted of a primary freeze-dried menu, supplementary snacks, frozen dinners, glycerol (sweetener), and a small amount of ice cream. Packaging, storage accommodations, supporting equipment, and acceptability of the food supplies are discussed. Recommendations for food programs for future long-term space missions are provided.

INTRODUCTION

In response to frequently reported negative reactions to food provisions for previous crews of long-term missions and simulations involving confinement, MDAC established the policy, early in the planning phase of the 90-day test, to select and provide food from the standpoint of acceptability. Acceptability was felt to be a function of menu diversity, mission duration, and initial reaction to the aesthetics of food consumption: flavor, color, consistency, and aroma.

This approach permitted the collection of information relevant to resolution of the question of whether attention to these factors could eliminate negative reactions to food provisions or whether such negative reactions could be expected to accompany all future long-term operational or simulative confinements.

PROCEDURES

Known processors of food provisions for space missions, or those known to have the capability, were contacted and requested to submit samples of their products. A list of potential suppliers was obtained through the cooperation of cognizant personnel at the U.S. Army, Natick Laboratories. From this review of products, their availability, diversity, and projected ability to meet criteria on microbiological control, Oregon Freeze-Dry, Inc., Albany, Oregon, was selected as the principal supplier of onboard food. Table 1 represents some of the freeze-dried menus that were provided.

Requirements placed upon the supplier of freeze-dried, uncompressed food consisted of: Microbiological control consistent with NASA/Army requirements, vacuum packaging, a 10-day menu cycle, and 2500 kilocalories/man/day. NASA/Army microbiological specifications were adhered to except for deviations on total aerobes (raised from 10 to 20/g) and total streptococcus counts (raised from

TABLE 1
REPRESENTATIVE MENU
FREEZE-DRIED

DAY 1 2,531 TOTAL CALORIES

BREAKFAST - 926 CALORIES

(49)* ORANGE JUICE
(57) GRAPENUTS WITH MILK
(73) SUGAR
(30) DICED HAM
(31) SCRAMBLED EGGS
(91) TOAST (2 SLICES)
(75) JELLY
(68) MILK (8 OZ)

LUNCH - 748 CALORIES

(23) PEA SOUP
(56) CRACKERS (6 CRACKERS)
(14) HAM AND GREEN BEANS
AU GRATIN WITH RICE
(96) PEANUT BUTTER COOKIES

DINNER - 856 CALORIES

(1) SLICED BEEF
(70) WITH GRAVY
(42) MASHED POTATOES
(35) CHOPPED BROCCOLI
(26) COTTAGE CHEESE WITH PEARS
(76) BROWNIES
(74) MARGARINE (1/2 TSP)

DAY 2 2,460 TOTAL CALORIES

BREAKFAST - 654 CALORIES

(55) STRAWBERRIES
(28) CREAMED BEEF
(90) ON TOAST (3 SLICES)
(94) CHOCOLATE MILK (6 OZ)

LUNCH - 733 CALORIES

(20) CONSOMME
(56) CRACKERS (6 CRACKERS)
(9) BEEF WITH RICE
(24) CARROT-RAISIN SALAD
WITH ALMONDS
(95) DATE FILLED OATMEAL
COOKIES

DINNER - 1,073 CALORIES

(4) SLICED HAM
(59) NOODLES WITH CHEESE SAUCE
(33) ASPARAGUS
(85) CHOCOLATE PUDDING
(74) MARGARINE (1/2 TSP)

DAY 3 2,563 TOTAL CALORIES

BREAKFAST - 697 CALORIES

(53)* DRIED OR STEWED PRUNES
(61) RALSTON WITH MILK
(73) SUGAR
(91) TOAST (2 SLICES)
(75) JELLY
(68) MILK (8 OZ)
(93) CHEESE SCRAMBLE

LUNCH - 724 CALORIES

(64) CHICKEN NOODLE SOUP
(56) CRACKERS (6 CRACKERS)
(13) CRAB IMPERIAL
(27) SWEET CORN

DINNER - 1,142 CALORIES

(19) SHRIMP COCKTAIL
(3) DICED CHICKEN
(71) WITH GRAVY
(58) NOODLES
(36) CARROTS, DICED
(77) COCONUT MACAROONS
(74) MARGARINE (1/2 TSP)

DAY 4 2,458 TOTAL CALORIES

BREAKFAST - 698 CALORIES

(48) GRAPEFRUIT JUICE
(60) OATMEAL WITH MILK
(73) SUGAR
(54) RAISINS
(31) SCRAMBLED EGGS
(91) TOAST (2 SLICES)
(75) JELLY

LUNCH - 934 CALORIES

(16) TUNA ALA NEPTUNE
(90) ON TOAST (2 SLICES)
(45) APPLESAUCE
(83) FRUITCAKE

DINNER - 826 CALORIES

(7) BEEF ALMONDINE WITH
MACARONI
(43) SPINACH
(50) CHEESE
(56) CRACKERS (6 CRACKERS)
(80) FILLED SUGAR WAFERS
(74) MARGARINE (1/2 TSP)

* ITEM IDENTIFICATION NUMBER

less than 10 to less than 20/g). Deviations were approved by the MDAC Medical Director. An additional 500 kilocalories of snacks were provided. These consisted of nuts, raisins, and candy bars.

For the frozen meals, Stouffer Foods, Cleveland, Ohio, was required to supply a minimum of 5 percent of the onboard meals, preferably complete dinners amounting to approximately 800 kcal/meal. NASA microbiological standards were to be met. Meals were to arrive in frozen form and were to be packaged to require no more than 4.3 cu ft of storage. The latter requirement was imposed because of the capacity of the onboard freezer.

In addition, at the request of crewman, 4 pints of commercially available ice cream were placed onboard.

The glycerol (a sweetening agent having nutrient value) was obtained as an experimental food supplement from Dr. J. Shapira, NASA Ames Research Center. Interest in the glycerol as a food additive centered upon its acceptability as a sweetening agent, as well as on its physiological resolution after ingestion. A full description of this experiment is provided in paper no. 21 of this symposium.

Data on food consumption were provided daily throughout the mission via the TSCL data transmission system available to onboard crewmen. Information thus transmitted consisted of crewman identification, food items consumed, percentages of foods not ingested, water volumes required for reconstitution, and relative acceptability ratings (1-9; 1 equals "poor," 9 equals "excellent").

Because of the late arrival of information on frozen foods, only the freeze-dried diet could be reported via the above-mentioned TSCL. Thus data on frozen food consumption were obtained verbally from crewmen.

Freeze-dehydrated foods were supplied in vacuum packages of a multilayer laminate which is used by the Army to package similar foods for combat field distribution. The packages consisted of an inner layer of polyethylene, an intermediate layer of aluminum foil, another layer of polyethylene, and an outer layer of Mylar, the latter a flammable plastic.

Within some packages of food items was a dish composed of a waxy plastic (also flammable) which was to be used for reconstitution purposes. Utensils available to the crew were made of stainless steel.

Frozen food was supplied in aluminum containers similar to TV dinner trays. These were covered with aluminum foil.

Ice cream was packaged in cylindrical paper containers.

Because of the flammability of packaging materials in the food program, special precautions were taken in their onboard storage and disposal. Freeze-dried packages were grouped into four-man meal packages. These were constrained with the use of fiber glass cable-tie cord and then overwrapped with three layers of heavy-duty aluminum foil. These were then stored in closed food

storage cabinets which had been examined and shielded to eliminate the danger of high voltage or other sources of ignition.

Additional plastic food reconstitution dishes were stored in specially provided, tightly covered aluminum containers which were also located away from ignition sources.

Frozen meals were placed inside the onboard commercial freezer without additional preparation, as were the cartons of ice cream.

Storage requirements for all onboard food provisions approximated 100 cu ft. Bulkiness and nonuniform package sizing of freeze-dehydrated food contributed to using approximately 40 cu ft more storage volume than originally allocated.

All foods requiring elevated temperatures to enhance palatability were heated in an onboard microwave oven. A Litton Industries Model 500 microwave oven was employed for food heating. Daily measurements of microwave emissions were made throughout the test. After modification of the front door seals by the addition of adhesive-backed aluminum foil tape, readings revealed consistent levels of 0.1 mW/cm² (average) with peak emissions up to 0.2 mW/cm². At no time during the 90-day test did emissions exceed 0.2 mW/cm².

RESULTS

Table 2 provides an indication of total food consumption for each crewman on day 90 of the mission and provides arithmetic means of daily caloric consumption for the crew over the entire 90-day duration. It can be seen that intake averaged 2,894 kcal/day/man. Differences in daily consumption among

TABLE 2
FOOD CONSUMPTION

Crewman	Kilocalories	Kilocalories
	90th Day	Mean 90 Days
1	2,067	2,741
2	2,412	2,822
3	4,041	2,878
4	3,561	3,137
Grand Mean		2,894 kilocalories

crewmembers are consistent with exercise regimens adjusted by crewmembers to their own individual requirements. This table reflects caloric values of all consumed foods excluding glycerol which was not a significant contributor to the total diet insofar as it was used for less than 10 percent of the mission duration and then only as a supplemental sweetener. Crew caloric intake is seen as inordinately high when compared with intake values from the previous 60-day test of a manned regenerative life support system wherein a mean daily consumption of under 2,000 kcal/man was reported. However, weight change data suggest that the 90-day values are consistent with the caloric requirements to meet actual crew work loads.

Referring to table 3, the overall acceptance of food on a rating scale extending from 1 through 9 was quite high - all food items on a group mean basis received ratings of 6 and above. This is an unusual finding for space simulations or operational missions and reflects increased attention given to the selection of food on the basis of palatability.

TABLE 3
90-DAY FREEZE-DRY FOOD ACCEPTANCE

Category	Crewman				Mean Modal Preference	Rank Order
	1	2	3	4		
Soups	7.50	7.80	7.20	7.00	7.38	5
Salads	7.33	6.33	8.00	8.66	7.58	4
Entrees	8.04	8.21	7.95	8.07	8.07	1
Dairy Products	7.21	7.14	7.28	6.92	7.14	7
Vegetables	7.07	6.69	7.23	7.53	7.13	8
Fruits and Juices	7.90	7.40	8.36	8.54	8.05	2
Grain Products	7.84	7.03	6.46	5.69	6.75	9
Desserts	7.79	6.08	7.55	7.26	7.17	6
Sauces and Condiments	8.80	7.80	7.80	7.60	8.00	3
Mean Modal Preferences	7.72	7.16	7.54	7.47		
Rank Order	1	4	2	3		

It should be noted that although group mean acceptance values are high, individual food items within the overall menu were occasionally ranked by individual crewman at lower levels. Food items falling in this category include such things as scrambled eggs and a gelatin dessert. Post-test crew remarks reflect the fact that scrambled eggs were rated low not because their palatability left something to be desired, but rather because it was the only form of egg available throughout the mission. The gelatin dessert was rated poor by three of four crewmen because of excessive sweetness.

Table 4 summarizes the frozen food available to the onboard crewmen during the mission. Forty-eight meals were provided by Stouffer Foods, Cleveland, Ohio, and were stored onboard in a 4.3 cu ft freezer. These foods (substitutes for dinners) were provided to the crew with instructions to utilize them as they saw fit approximately once weekly throughout the mission.

Crewmen chose to use these foods with a frequency of approximately once per week and otherwise employed them as a means of celebrating special occasions encountered during the mission. One such special occasion was a birthday celebration held for one of the onboard crewmen.

Generally the frozen foods were well accepted by all crewmen but the crew indicated that they could have done without them had they been required to do so. Since they were available, they found them a welcome diversion from the freeze-dehydrated primary food menu. Negative remarks reflected the feeling that, when compared with the primary diet, the frozen meals were overly rich. This combined with differences in strength of seasoning apparently resulted in some minor gastrointestinal difficulties. Interestingly, frozen meals were prepared utilizing the microwave oven even though the use of that piece of equipment with the frozen meals required frequent pulsing. Our crew did not report that this was an annoyance as have others.

Microbiological Quality

All freeze-dried and frozen food items were tested for microbiological quality by the vendors. The following criteria were specified and met by the vendor's products:

- A. Total aerobic count = less than 20,000/g
- B. Total coliform count = less than 10/g
- C. Total fecal coliform count = none/g
- D. Total Streptococcus count = less than 20/g
- E. Total coagulase positive Staphylococcus count = none/5g
- F. Total Salmonella count = none/10g

Spoilage

There was little if any spoilage of freeze-dried or frozen foods during the test. Several commercially packaged snack food items were found to be stale or otherwise unacceptable by the crew. Candy bars and cookies containing nut meats

TABLE 4
FROZEN FOOD
(8 OF EACH)

<u>DINNER NO.</u>	<u>CONSTITUENTS</u>	<u>WEIGHT (OZ)</u>	<u>ESTIMATED KILOCALORIES</u>
1	SIRLOIN STEAK	8	663
	CREAMY POTATO BAKE	4	120
	ASPARAGUS SPEARS	3	20
		<hr/>	<hr/>
		15	803
2	POT ROAST OF BEEF	3	265
	BEEF GRAVY	2	50
	DUCHESSE POTATOES	3.5	120
	GLAZED CARROTS	3	140
		<hr/>	<hr/>
		11.5	575
3	BEEF STEW	10	1,070
	SPICED PEACHES (2 HALVES)	4.5	90
		<hr/>	<hr/>
		14.5	1,160
4	BAKED CHICKEN BREAST	5	125
	CHICKEN GRAVY	2	90
	RICE	3	210
	CORN	3	60
		<hr/>	<hr/>
		13	485
5	LAMB CHOPS (2)	8	630
	ESCALLOPED APPLES	4	265
	GREEN BEANS	3	20
		<hr/>	<hr/>
		15	915
6	CHICKEN AND DUMPLINGS	10	585
	PEAS	3	60
		<hr/>	<hr/>
		13	645

were found to have the shortest shelf life. The crew's discovery of a few fly larvae in the raisins provided an interesting diversion for both onboard and outside simulator personnel. Vacuum packaging, addition of antioxidants, and fresh delivery immediately before test start would alleviate this problem.

Food Waste Management

Reduction of food waste was accomplished primarily by careful selection, trimming, and apportioning of both freeze-dried and frozen food items by the respective vendors. In addition, the crew was instructed in and fully accepted the inelegant but effective technique of licking their plastic food trays prior to spraying them with disinfectant. Leftover food waste exceeding several grams was scraped from the trays into a No. 2 can for canning following a heavy spray of the contents with disinfectant (8-hydroxyquinoline sulfate, 5 percent aqueous solution).

Post-test microbiological assays of treated food waste revealed complete sterilization of the food trays, but only partial suppression of growth in canned waste. Upon inspection of the can contents, it was evident that several cans had not been treated or had not been treated with sufficient disinfectant to completely inactivate the contents.

Sprayed food trays (plastic) were stowed in environmentally sealed aluminum boxes. Each box held approximately 500 trays. By counting the number of trays and observing the box fill dates, an average use rate of 2 trays/man/meal was calculated.

This figure is lower than pretest estimates and the crew confirmed saving of trays by multiple-use techniques such as using the same tray for preparation of more than one item or using one tray for preparing a double portion. The use rate of stowed trays would have been even lower had more care been taken during handling of several freeze-dried food items already packaged in trays. These trays had become cracked during the bundling and wrapping operations before stocking of the simulator.

CONCLUSIONS

Freeze-dehydrated food is an acceptable diet for long-duration missions.

It may be desirable to defray the monotony of a single diet with foods prepared and stored utilizing other techniques.

Reheating of reconstituted freeze-dehydrated food apparently served to increase the acceptability of this diet. The microwave oven was simple to use and quite effective in performing this function.

When employing combined diets, it may be necessary to adjust seasoning and "richness" to achieve greater acceptability.

Greater attention must be given to the selection of containers and food packaging materials from the dual standpoints of flammability and storage density.

Negative reactions to food provisions are a phenomenon which can be eliminated through the combined efforts of food selection oriented toward palatability, the provision and utilization of a means whereby foods can be heated to acceptable serving temperatures, and provision of an acceptable variety in available diets.

USE OF GLYCEROL AS A DIET SUPPLEMENT DURING A NINETY-DAY MANNED TEST

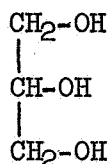
By Jacob Shapira
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SUMMARY

The crewmen during a ninety-day manned test ingested a glycerol solution mixed with various other food materials during two different five-day periods. The glycerol diet supplement was judged to be "better than average" and did not lead to an elevation in serum free glycerol. An erratic and inconsistent rise in urine-free glycerol, as determined by an enzymatic method, was observed. As expected, there was no nausea or ill effect observed during the use of free glycerol as a food adjunct.

INTRODUCTION

Glycerol dates from the earliest days of organic chemistry when its isolation from fat as an individual compound was first reported by Scheele in 1779 (ref. 1). Its name derives from the Greek "glukos," meaning sweet, since it had a sweetness almost as intense as sugar. Later, its structure was shown to be



which in most aspects is quite similar to the structure of sugars.

Along with being found in food as a component of fat, free glycerol is present in small amounts in fermented materials such as beer, wine, and bread. Further, it is now commonly added in relatively small amounts to foods in which it is not normally present to confer desirable physical properties. It is also utilized because of its desirable solvent properties in the formulation of a wide variety of pharmaceutical preparations and is useful in the compounding of food flavorings. Glycerol is "generally recognized as safe" by the U.S. Food and Drug Administration.

It was not until 1902 that Cremer demonstrated that glycerol was processed by the body to produce glucose when he reported that diabetics excreted additional sugar when fed glycerol (ref. 2). This gluconeogenic attribute of glycerol was later confirmed by Catron and Lewis in 1929 with the demonstration that ingestion of glycerol by fasting rats led to an increase in liver glycogen (ref. 3). Since then, extensive studies have been conducted which repeatedly show that the most important pathway of glycerol metabolism involves its rapid conversion in the body to glucose.

The current confidence regarding the low oral toxicity of pure glycerol has not always existed. It is possible that early preparations contained by-products which resulted in reports of nausea, vomiting, and injurious effects. It remained for Johnson, Carlson, and Johnson in 1933 to disprove effectively injurious effects in animals and man when significant amounts of glycerol were consumed (ref. 4). They reported that after extensive preliminary testing in rats and dogs consuming almost one-half of their diet as glycerol, they then fed 110 g of glycerol per day to ten men and four women for a period of fifty days. This amount of glycerol could provide about 475 kcal which would amount to almost 20% of the daily calorie requirement of the subjects. There were no significant changes in the blood and urine analyses performed nor was there a change in the basal metabolic rate. No evidence was observed of diarrhea, abnormal intestinal activity, sleeplessness, or excitement - effects which have been previously reported by others.

Based upon the report of Johnson, Carlson, and Johnson (ref. 4), and other subsequent reports of the innocuous effect of the oral ingestion of glycerol by man, it was decided to investigate the suitability of glycerol as a potential physicochemically regenerated food during long-duration space missions. Two other aspects of the problem, aside from its nutritive qualities, had to be investigated: the feasibility of its manufacture from waste during the mission and its psychological acceptability.

The problem of manufacture has been pursued to the point where currently it can be stated that the feasibility of the following synthetic sequence has been demonstrated: (1) reaction of respiratory carbon dioxide with hydrogen to yield methane; (2) oxidation of methane to formaldehyde; (3) self-condensation of formaldehyde to produce formose sugars; and (4) hydrogenolysis of formose sugars to give glycerol plus other low-molecular-weight polyols. Separation of pure glycerol from the mixture remains to be accomplished.

The problem of acceptability of glycerol under simulated aerospace conditions is the subject of this report. The crewmen of the ninety-day test agreed that they would consume 40 g per day of food grade glycerol in four 10-g doses during two different five-day periods. They would also report their evaluation of different flavorings and methods of ingestion. Concurrently, analyses of blood and urine samples would be conducted to determine the possible physiological effects of this supplement to their diet.

MATERIALS AND METHODS

The glycerol used was Reagent Grade per the specifications of the American Chemical Society. It was diluted with distilled water to give a solution containing 1 g glycerol per ml of final volume. Lemon and lime flavors were reconstituted juices obtained from a local supermarket. The composition of other foodstuffs such as "Kool-Aid," dehydrated coffee and tea, used by the crew in combination with the glycerol are reported in paper no. 20 of this compilation.

The glycerol solution was provided in a 1-liter plastic automatic dispenser set to deliver 10 ml of the solution each time. The crew was instructed to mix

this quantity of solution with a single flavor or mixture of flavors, dilute with at least five volumes of water or beverage, and consume. The sweetness of 10 ml of the solution was equivalent to about 1 teaspoon of sucrose. The crew was also instructed to allow at least 2 hours between ingestions, which could be before, during, after, or between meals. They were to record the total volume of liquid consumed and their subjective evaluation of the mixture using the following five-point scale:

1 = like very much

2 = better than average

3 = acceptable

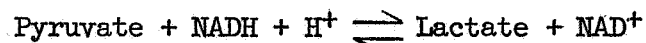
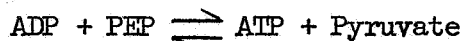
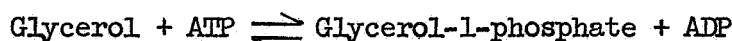
4 = might try again

5 = will never try again

This five-point scale satisfied the requirements of this experiment and is similar to a standard hedonic scale used in food preference studies.

The blood samples used were portions of the weekly collections described in paper no. 45 of this compilation. As a normal part of the serum lipid study performed on the samples by NMRI, values for serum-free glycerol were determined and are reported herein.

Analysis of weekly urine samples for free glycerol was kindly performed by D. Myers of MDAC using a variation of the Boehringer Mannheim Corp. protocol for the enzymatic analysis of serum glycerol utilizing the following reactions:



The reduction in absorbancy of the solution at 366 nm due to the loss of NADH was equated with the glycerol present.

The accuracy of the method for urine samples and the recovery of added glycerol is indicated by the following excerpt from a letter by S. Klotzsh, Chief Chemist, Boehringer Mannheim Corp.

"Following the methodology for serum, our laboratory assayed three different urine samples (0.5 ml per test) and also the same specimens with the addition of 1 mg and 2 mg% of glycerol:

Sample	Recovered Glycerol (mg%)		
	1	2	3
Without addition	0.21	0.28	0.44
Plus 10 µg glycerol/ml	1.25	1.28	1.37
Plus 20 µg glycerol/ml	2.20	2.19	2.48
percent recovery	103, 100	100, 96	95, 102

The urine was filtered prior to use to exclude particle interferences in the measurement of optical density. A difference of time or rate in comparison to serum samples was not observed."

RESULTS

Glycerol as a food additive was quite acceptable to the crewmen. During the first period in which they had access to this material, there was considerable experimentation with various flavorings. In addition to its formulation as beverages, on a number of occasions it was added to cereal and fruits with good reports. As can be seen from table I, the recorded evaluations indicated that it was considered to be "better than average."

During the second period of ingestion, the acceptability declined somewhat to approximately "average." The degree of experimentation with flavors was very much reduced and one of the crewmen was satisfied merely to dilute the glycerol with water throughout this phase. None of the crewmen in either of the test periods found any formulation to be unacceptable. General comments at the end of the test indicated that the crewmen thought the taste of glycerol was detectably different from sucrose. Its convenience as a sweetener was thought to be desirable.

Analysis of blood samples drawn immediately after the period of glycerol consumption indicated a nonsignificant rise ($P > 0.1$, t test) in the level of free glycerol when compared with the levels observed one week prior to or after the test (table II). Even when all base-line values were pooled for statistical analysis, the increase was not significant.

The results obtained with urine samples are more difficult to interpret. There is a highly significant rise in the amount of glycerol excreted (table II). However, there is a wide difference in the levels of excretion by the different crewmen. This may be due to individual physiological variations but other factors may also have had an effect. For instance, during the last few days of each test period, there were deviations from the protocol with regard to the time between consumptions and the amount consumed at a given time. Also, during the second test period, because of unanticipated losses of glycerol solution, not all subjects held to the regime until the end of the test; in

fact, crewman 1 terminated glycerol ingestion after only three days because of the shortage. Further, some crewmen consumed "double doses" or single doses in rapid succession. It can be predicted that this would result in elevated excretion of glycerol.

DISCUSSION

As was expected, it was found that even with the stress of the ninety-day test, acceptability of glycerol was high. Since it is known that glycerol is very rapidly metabolized by the body to primarily glucose and to a lesser degree directly to carbon dioxide, it is not surprising that no elevation in serum-free glycerol was observed several hours after the last ingestion. In theory, the amount consumed could give rise to a transitory threefold increase in the serum level of glycerol, but this would be observed only if absorption was very rapid and measurements were performed within minutes after consumption.

It is thought that the rate of excretion of glycerol into the urine is directly proportional to the serum concentration of free glycerol. This may help to explain the difference observed between the amounts excreted before and after the first test period and the corresponding values obtained during the second test period. The mean volume of urine during the collection day of the first test period was 1140 ± 265 ml whereas it was 1940 ± 205 ml during the second period. The difference is significant ($P < 0.05$, t test). The same situation obtained with regard to the excretion of glycerol. During the base-line periods of the first glycerol ingestion, total excretion of glycerol was 2.24 ± 0.25 mg per day while during the second period, it was 4.43 ± 0.45 mg per day. Again, the increase was highly significant ($P < 0.01$, t test). Thus, the normal excretion rate of glycerol seems to parallel the total volume of urine, a situation which would be expected if glycerol excretion were a passive process.

The passive nature of glycerol excretion does not explain the extent of the elevation observed during test. The wide variations in glycerol excretion complicate the situation. However, the fact that the relative amounts excreted by each crewman during the two different test periods was essentially in the same order would suggest individual physiological differences. Further studies are planned. In any case, the average excretion of glycerol during test represented less than 0.1% of the ingested amount and can be considered negligible.

Because of shortage of glycerol, crewman 1 terminated his consumption of glycerol about 10 hours before beginning the collection of urine. As seen from table II, his urinary excretion had returned to normal values, which indicates a very short retention time for excess glycerol in the body. This is consistent with known rates of glycerol metabolism as determined by studies involving radioactive glycerol and measurement of the excretion of radioactive metabolites such as carbon dioxide (ref. 5).

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TABLE I.- ACCEPTABILITY OF GLYCEROL AS A FOOD ADDITIVE

Crewman	6/25/70 to 6/30/70		8/20/70 to 8/25/70	
	Number of consumptions	Rating*	Number of consumptions	Rating*
1	20	**	12	2.9 ± 0.1
2	20	2.1 ± 0.2	14	3.0 ± 0.1
3	14	2.2 ± 0.1	15	2.9 ± 0.1
4	20	1.3 ± 0.2	16	2.9 ± 0.1

*Mean ± SEM. See text for description of five-point rating scale.

**Crewman failed to give numerical rating.

TABLE II.- SERUM-FREE AND URINE-FREE GLYCEROL

Crewman Date	Serum-free glycerol, mg%				Urine-free glycerol, mg/24 hr			
	1	2	3	4	1	2	3	4
6/23	0.7	0.8	0.9	0.6	2.7	1.9	1.7	3.7
6/30 (TEST)	0.6	0.7	1.2	0.8	18.4	39.0	106.0	2.8
7/7	0.7	0.7	0.9	1.0	1.7	2.5	2.8	1.6
8/18	1.2	0.9	0.9	1.2	4.4	3.0	5.9	5.0
8/25 (TEST)	*1.2	1.1	9.1	4.2	*3.3	30.7	65.7	5.8
9/1	1.1	0.7	1.3	0.9	5.5	2.9	5.6	3.1

*Crewman terminated consumption of glycerol about 10 hours before collection of urine.

MASS BALANCE DATA

By J. K. Jackson, L. G. Barr, and J. F. Harkee

McDonnell Douglas Astronautics Company

SUMMARY

The overall mass balance for the SSS in the 90-day test may be evaluated by considering the potable water recovery unit, the wash water recovery unit, the atmosphere supply, and the oxygen recovery units. Over the 90-day period, urine production averaged 13.09 lb/day and respiration and perspiration losses by the crew, 11.70 lb/day. The cabin latent load was increased by wash water evaporation of 560.3 lb and excess humidity generated by the solid amine unit of 1,075.1 lb, so that a total of 2,688.7 lb (or 29.87 lb/day) of humidity condensate was removed from the cabin. Potable water production, certified for crew consumption, was 2,356.7 lb (26.19 lb/day), of which 2,044.6 lb (22.72 lb/day) was actually consumed by the crew. Of this potable water production, 1,308.6 lb was produced by the VD-VF unit during its days of operation and 1,048.1 lb by the wick evaporator or from humidity condensate. The humidity condensate was also used to supply the solid amine unit (1,148.0 lb), for makeup to the VD-VF unit (643.8 lb) to support its feed requirements, for makeup to the wash water unit (512.9 lb), and other miscellaneous uses.

The wash water recovery unit produced 10,447.6 lb (116.08 lb/day) of water at the dispenser, of which 560.3 lb was lost by evaporation, as has been mentioned.

The atmospheric gas supply furnished 862.0 lb of oxygen and 278.9 lb of nitrogen to the SSS. Part of the oxygen (137.4 lb) and all of the nitrogen went into losses, leakage, and atmospheric samples, leaving a balance of 724.6 lb (8.05 lb/day) of metabolic oxygen consumption by the crew. The oxygen was primarily furnished by water electrolysis, including 22.4 lb by the Allis-Chalmers unit, 566.0 lb by the Lockheed unit, and 258.3 lb by the commercial electrolyzer serving as a backup. The balance of 15.3 lb was supplied by high-pressure storage. Water for the Allis-Chalmers and Lockheed units was supplied by the Sabatier reactor (332.0 lb) or from an onboard storage reservoir (330.0 lb). A total of 81.0 lb of hydrogen was supplied by electrolysis for the Sabatier reactor, with a balance of 24.9 lb being vented during periods of inoperation of the Sabatier.

The CO₂ concentrators removed a total of 752.0 lb (8.36 lb/day) of CO₂ from the cabin. A total of 636.9 lb was processed through the Sabatier reactor along with the 81.0 lb of hydrogen. The balance was vented overboard.

INTRODUCTION

The system mass balance has been determined from performance data on potable water recovery, wash water recovery, the water electrolysis units, two-gas control, Sabatier reactor, and CO₂ concentrators, and from input/output data on the crewmen. These life support subsystems have been previously described. Determination of the mass balances involved detailed consideration of the operating modes of the various units as they varied during the test. The overall mass balance presents valuable information on the average input and output parameters of the crewmen. Subsystem and unit performance can best be evaluated by examining in detail various segments of the mission during which representative combinations of operating modes occurred. Because of the accuracy of instrumentation and the many locations in which temporary storage occurred, these segments must be long enough to obtain accurate averages.

SYSTEM DESCRIPTION

Mass balance data were determined by a review of data from many sources. Flowmeters and totalizers were installed in most major gas and water transfer lines. Quantity measurements in potable and wash water tanks were made continuously by strain gage load cells supporting the tanks. Quantities in other tanks were measured before and after the test. The two-gas control used pulse counters to total the amount of gas supplied by the flight-type electrolysis units, the backup (Stuart) electrolysis unit, and high-pressure oxygen and nitrogen facilities. Records were kept, particularly in the latter portion of the test, of water supplied to the Lockheed electrolysis unit, which provided an improved calibration of the two-gas oxygen pulse counter. Some variation in the water flowmeter calibrations was encountered in the potable water system. Fortunately, very detailed and accurate records were kept of water transfers by the inside crew. Much of the water system mass balance depended on these records.

TEST RESULTS

Discussion of mass balance test data will include consideration of the potable water recovery, the wash water recovery, the atmosphere supply, and the atmosphere recovery units. From these data and other records, the crew input/output requirements can be determined. Each of these areas will be discussed in detail.

Potable Water Recovery

The potable water recovery unit represented an integration of the VD-VF radioisotope heated unit and the wick evaporator for recovery of water from

urine. Water was also recovered from humidity condensate. Final purification of water was accomplished by multifiltration and storage was in four heated use tanks. When possible, the water produced by the VD-VF unit was pumped directly to a use tank; when potability standards were not met directly, this water was also processed by multifiltration. The usual requirement for reprocessing was a positive microbial sample or excessive ammonium ion concentration in the VD-VF condensate. These variations have already been discussed in detail in paper number 5.

Figure 1 shows the overall potable water balance for the 90-day period. During this time 1,178.5 lb of urine were produced, averaging 13.09 lb/day. The respiration and perspiration losses of the crew were determined by subtraction of recorded data on water sources from total water production, and were found to be 1,053.3 lb (11.70 lb/day). Contributing to the total load on the humidity control separator condenser were also 680 lb of urine vapors from the wick evaporator, 560.3 lb of wash water evaporation, and 1,075.1 lb of water vapor from the exhaust of the solid amine unit. The total humidity condensate was 3,356.4 lb (37.29 lb/day) of which 3,172.4 lb was removed by the Lockheed hydrophilic/hydrophobic condenser-separator, 76.0 lb by the silica gel desorbate condenser, and 108.0 lb by the condensation that occurred in the thermal control unit. The Lockheed separator actually separated 2,647.0 lb from the air stream, allowing the balance of 525.4 lb to pass through; this was separated downstream by gravitational forces. The separation efficiency was therefore 83.5 percent, which was undoubtedly considerably reduced by the unexpectedly high condensation rate which was several times the design value.

Unprocessed humidity condensate was supplied to a number of units which did not require water meeting potability standards. These included makeup water to the solid amine boiler (1,148 lb), makeup for the evaporation in the wash water unit (512.9 lb), and makeup to the VD-VF unit (643.8 lb). The latter was required because the feed rate to the VD-VF boiler must be held constant to accommodate the constant heat input rate of the radioisotope heaters. Since it was necessary occasionally to reprocess urine in the wick evaporator that had already been diluted for feed to the VD-VF unit, the 700 lb of feed to the wick evaporator included some humidity condensate as well as urine.

Where product water from the VD-VF unit met potability standards, it was pumped directly to the heated use tanks. This included 460.0 lb. When these standards were not met, 848.6 lb of VD-VF water was processed by multifiltration. Of the total 2,356.7 lb (26.19 lb/day) of water certified for potability during the test, a net increase of 81.9 lb occurred in the four use tanks and 2,044.6 lb (22.72 lb/day) were consumed by the crew. Of the balance, 49.8 lb were passed out of the chamber for analysis, 81.4 lb were returned to the wash water unit, 43.4 lb were added to the VD-VF feed (possibly being reprocessed after onboard sampling) and 55.6 lb were transferred overboard as contaminated waste.

Of the water transferred to the solid amine unit (1,148.0 lb) and not returned to the cabin as humidity (1,075.1 lb), a total of 55 lb were

transferred to the wash water unit, 12.2 lb were removed with the CO₂ produced, and 5.7 lb were transferred overboard.

To show variations in water circulation during various operating modes, some segments of the total period were examined in more detail. Figure 2 presents one of these segments, for the 8-day period, test days 5 through 12. During this period the solid amine and VD-VF units were operating and no wick evaporator operation occurred. In deriving this chart, average values were used for urine production, crew latent loss, wash water evaporation, urinal flush water, VD-VF vent losses, and boiler residuals. Other values represent recorded data during this period. It will be noted that VD-VF production averaged 20.58 lb/day, and none of this product was multifiltered. The total humidity condensate averaged 30.47 lb/day, of which 12.70 lb/day resulted from the solid amine unit. Diluent water to the VD-VF feed was 58.48 lb or 7.31 lb/day most of which was provided from the humidity condensate.

Figure 3 shows the 8-day period from test day 46 through 53, when the wick evaporator and solid amine units were operating and no VD-VF operation occurred. Again, 90-day average values were used for urine production, wash water evaporation, urinal flush water, and wick evaporation residual solids. Actual data were used for crew consumption (23.35 lb/day) and average metabolic water production was used to determine crew latent loss of 12.33 lb/day. All other data represent measured values. During this period, the solid amine unit contribution to cabin humidity was 8.48 lb/day. The wick evaporator was processing urine which was previously diluted for VD-VF feed, averaging 21.93 lb/day. The total humidity condensation rate was 48.83 lb/day, which was one of the peak periods during the test. An average of 26.09 lb/day was certified for crew consumption.

Figure 4 shows data for the final 10 days of the test. On day 81 the VD-VF and the solid amine units were both shut down for the balance of the test. This period represents operation on the molecular sieve CO₂ concentrator and the wick evaporator. At the beginning of this period approximately 65.75 lb of diluted urine was available which was processed in the wick evaporator as well as the urine produced. No further dilution of the urine occurred from humidity condensate. Also, the crew was actively preparing for the end of the test, and a number of extra cycles of the washer/dryer were performed, increasing the wash water evaporation loss to 8.67 lb/day. Even so, the total humidity condensate was down to 20.84 lb/day because of the shutdown of the solid amine unit. The evaporation rate of the wick evaporator was 22.0 lb/day, producing a total condensation of 42.84 lb/day. Of this, the net inventory in the two potable holding tanks was increased by 81 lb and the potable use tanks by 44 lb, averaging an increase of 12.5 lb/day.

Wash Water Recovery

The mass balance for the wash water recovery unit is shown on figure 5. During the 90-day period, a total of 10,447.6 lb (116.08 lb/day) was dispensed

by the unit. Of this 560.3 lb (about 5 percent) was lost by evaporation. Much of this was probably from the clothes dryer and sponge bathing. Makeup water included 797.8 lb from various sources to compensate for evaporation losses as well as 207.4 lb used for urinal flush water and 101.4 lb of other losses. The net change in inventory in the holding and use tanks was a loss of 75 lb. About 500 lb of wash water was reprocessed after changes in multifiltration columns to remove accumulated contaminants.

Atmospheric Gas Supply

Figure 6 shows the overall mass balance for the atmospheric gas supply. Oxygen for this supply and hydrogen for the Sabatier reactor were normally generated by water electrolysis. Initially this was done by a flight-type unit built by Allis-Chalmers and installed inside the SSS. However, as explained in paper number 14, this unit soon had operational problems and was responsible for generation of only 22.4 lb of oxygen and 2.8 lb of hydrogen. Most of the balance of the test depended upon the Lockheed unit which was installed outside the SSS and generated 566.02 lb of oxygen and 70.75 lb of hydrogen. These units were supplied with water produced by the Sabatier reactor (332 lb) or from a storage reservoir inside the chamber (330 lb). The hydrogen generated was normally used by the Sabatier reactor, although it was shut-down for periods of time during which it was necessary to vent 15.6 lb.

When neither flight-type water electrolysis unit was able to meet cabin requirements, supplementary oxygen and hydrogen were produced by the commercial Stuart electrolysis unit. This amounted to 258.3 lb of oxygen and 23.00 lb of hydrogen. Since the Stuart unit was manually controlled at a fixed electrolysis rate, the excess gas generated was vented, and measurements were not made of the amount of water supplied to the unit.

In addition to the 846.7 lb of oxygen generated by electrolysis, 15.3 lb were supplied from the high-pressure storage unit. This was done once on day 6 when the oxygen setpoint of the two-gas control was increased by 10 torr, and approximately 4 lb of oxygen were added manually to compensate. Other usages of gaseous oxygen occurred during several short periods when none of the electrolysis units were functioning.

Nitrogen was supplied from high-pressure gaseous storage and controlled by the two-gas control. Total nitrogen usage was determined from the pulse counter totalizer on this unit. This amounted to 278.9 lb, or 3.10 lb/day. Of this input, 2.30 lb of N_2 and 1.10 lb of O_2 were removed from the SSS for atmospheric analysis. The balance of the nitrogen is indicative of losses and leakage. Average analysis of the CO_2 output of the molecular sieve and solid amine units indicates a total of 20.4 lb of N_2 and 10.0 lb of O_2 were removed with this gas. Other losses may have occurred by undetected leaks in the VD-VF vent, the commode sealing valve, the commode fecal sampler, the dry waste can vent to annulus, and other sources. Data are not available to define these values. Previous experience with the SSS indicates that basic chamber leakage is normally very low. In any event the total of unaccounted losses and leakage is 256.2 lb (2.85 lb/day) of nitrogen and 126.3 lb (1.40

lb/day) of oxygen. The remaining 724.6 lb of the oxygen (8.05 lb/day) is accounted for by crew metabolic consumption.

Atmosphere Recovery

The mass balance for atmosphere recovery is shown on figure 7 for the 90-day period. In this system, CO₂ is removed from the cabin either by the solid amine or the molecular sieve unit. Purity of the CO₂ removed was determined by periodic analysis of samples taken outside the chamber. Average values of these analyses were used to determine the nitrogen and oxygen removal with the CO₂. Also, the effluent CO₂ from the solid amine unit contained excess water. After the test, 5.5 lb of water were removed from the CO₂ accumulator. Additional water vapor was present to establish an average dewpoint of the CO₂ of about 75°F. This resulted in removal of about 12.2 lb of water from the SSS during the 69.5 days of operation. The molecular sieve unit provided CO₂ with a dewpoint of about -50°F, and therefore removed very little water from the cabin although there may have been some water entrapped in the beds.

The Sabatier reactor was normally operated with all the produced CO₂ being processed through it. However, low CO₂ feed rates were used during a period of intermittent operation before the catalyst change, and venting of CO₂ occurred during periods when it was not operating. During one period when catalyst poisoning was suspected, 28.3 lb of bottled CO₂ was furnished to the reactor in an attempt to regain catalyst activity and CO₂ removed from the cabin was vented.

The CO₂ feed to the Sabatier reactor necessarily included O₂, N₂, and H₂O as impurities. Analysis indicated the hydrogen feed to be essentially pure. The exhaust gas was passed through a water bath, in which the increase in water content was noted to determine the loss of water in the exhaust vent, and measured by wet test meter. Average of periodic analyses determined the vent gas composition, which confirmed the presence of nitrogen and CO₂. Normally the oxygen content was very low, indicating that it had reacted with hydrogen in the reactor to produce product water. Unreacted hydrogen was vented, including some during short periods of reactor operation with excess hydrogen to produce catalyst reduction. The Sabatier reactor operated for a total of 80 days, producing 332.0 lb of water for an average rate of 4.10 lb/day. Peak rates were somewhat higher.

Crew Input/Output

The input/output of the four crewmen is shown on figure 8. As indicated, the input included averages of 8.05 lb/day of oxygen, 22.7 lb/day of water, and 5.4 lb/day of food. Most of this food (approximately 90 percent) was freeze dehydrated. The crewmen showed a net weight increase of 2.25 lb.

Output of the crewmen included 8.47 lb/day of CO₂. The derived respiratory quotient was therefore 0.76. Crew respiration and perspiration averaged 11.70 lb/day. The urine output of 1,178.5 lb was found to include 49.8 lb of solids and 1,128.7 lb of reclaimable water, for an average of 12.54 lb/day. The reclaimable water in urine, respiration and perspiration was therefore 24.24 lb/day; 1.54 lb/day or 138.6 lb more than the potable water consumption. Water was collected in the commode freeze traps (52.2 lb) and 26.6 lb of dried fecal solids in the commode. Total fecal production was therefore 78.8 lb or 0.93 lb/day.

OVERALL POTABLE WATER SYSTEM MASS BALANCE

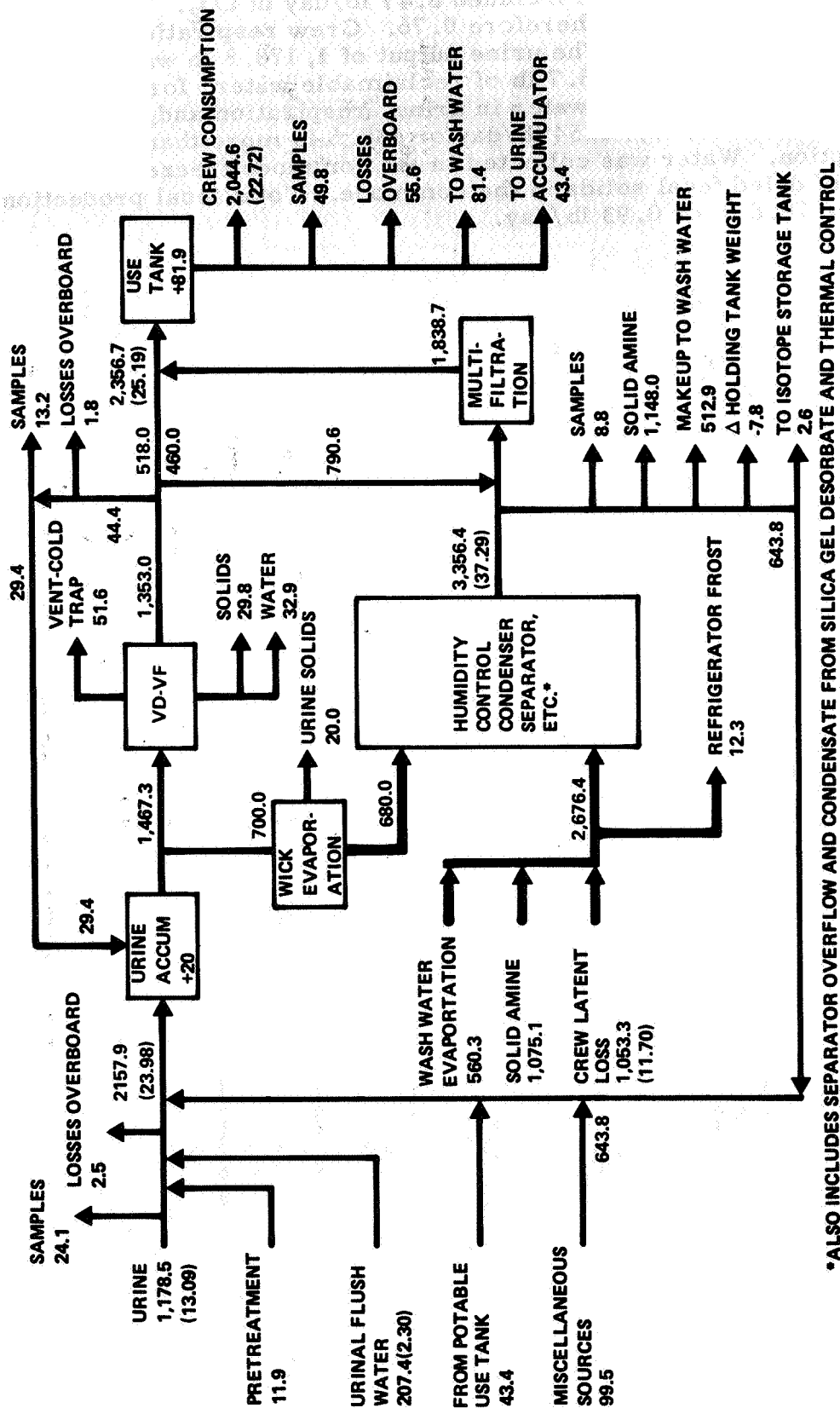


Figure 1

POTABLE WATER SYSTEM MASS BALANCE

TEST DAY 5 THROUGH 12 (8 DAYS)

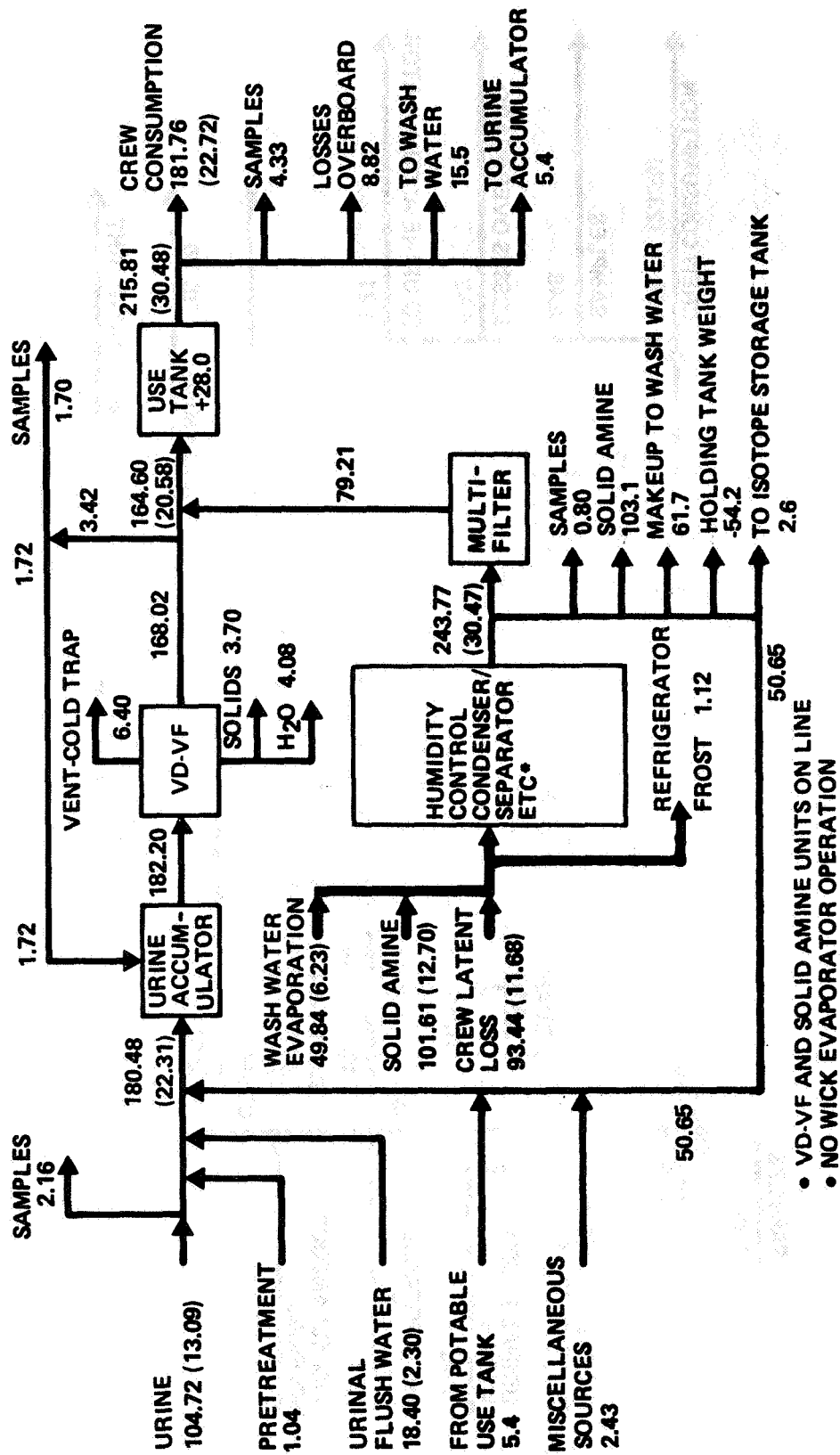
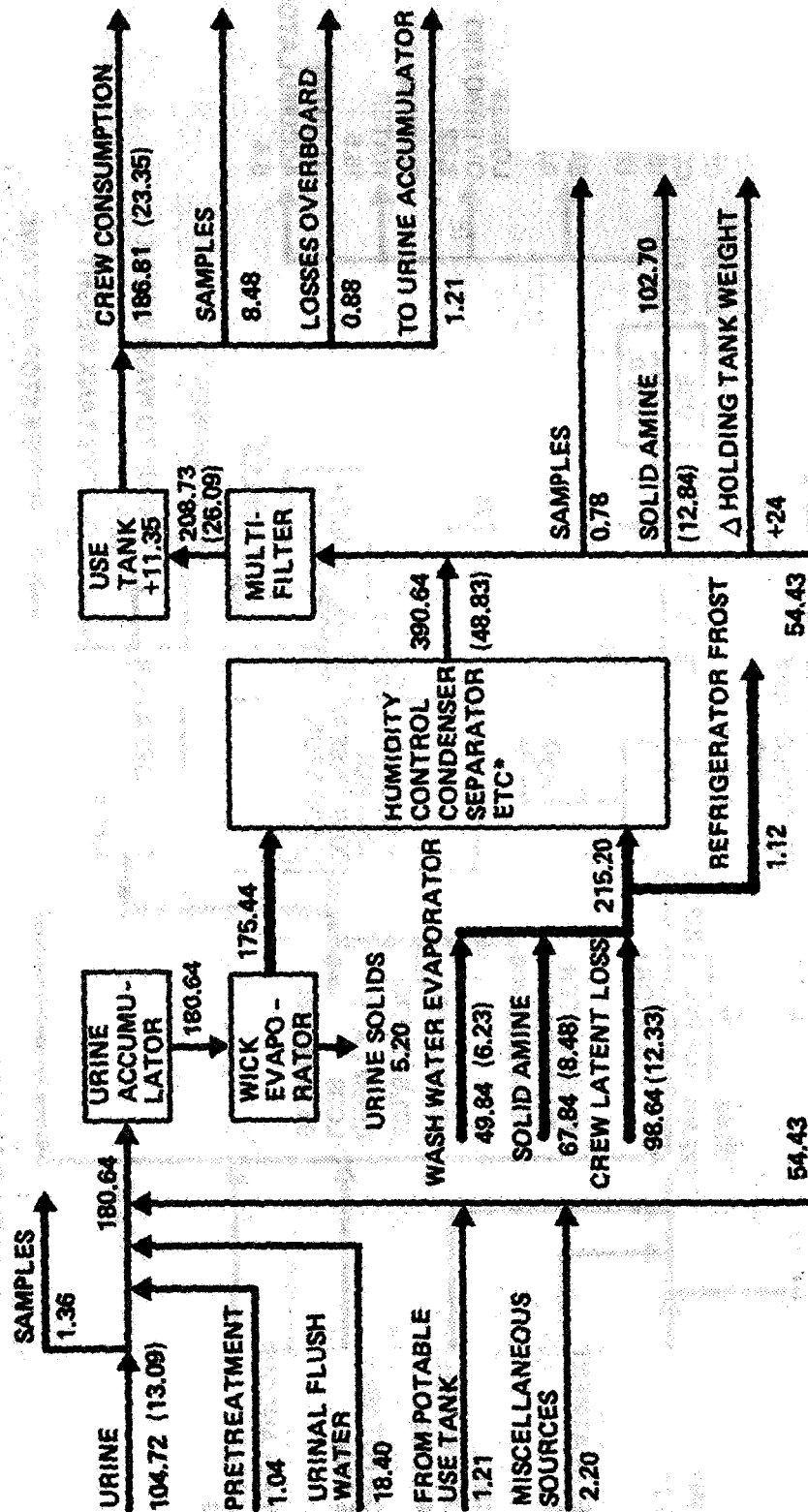


Figure 2

POTABLE WATER SYSTEM MASS BALANCE

TEST DAY 46 THROUGH 53 (8 DAYS)

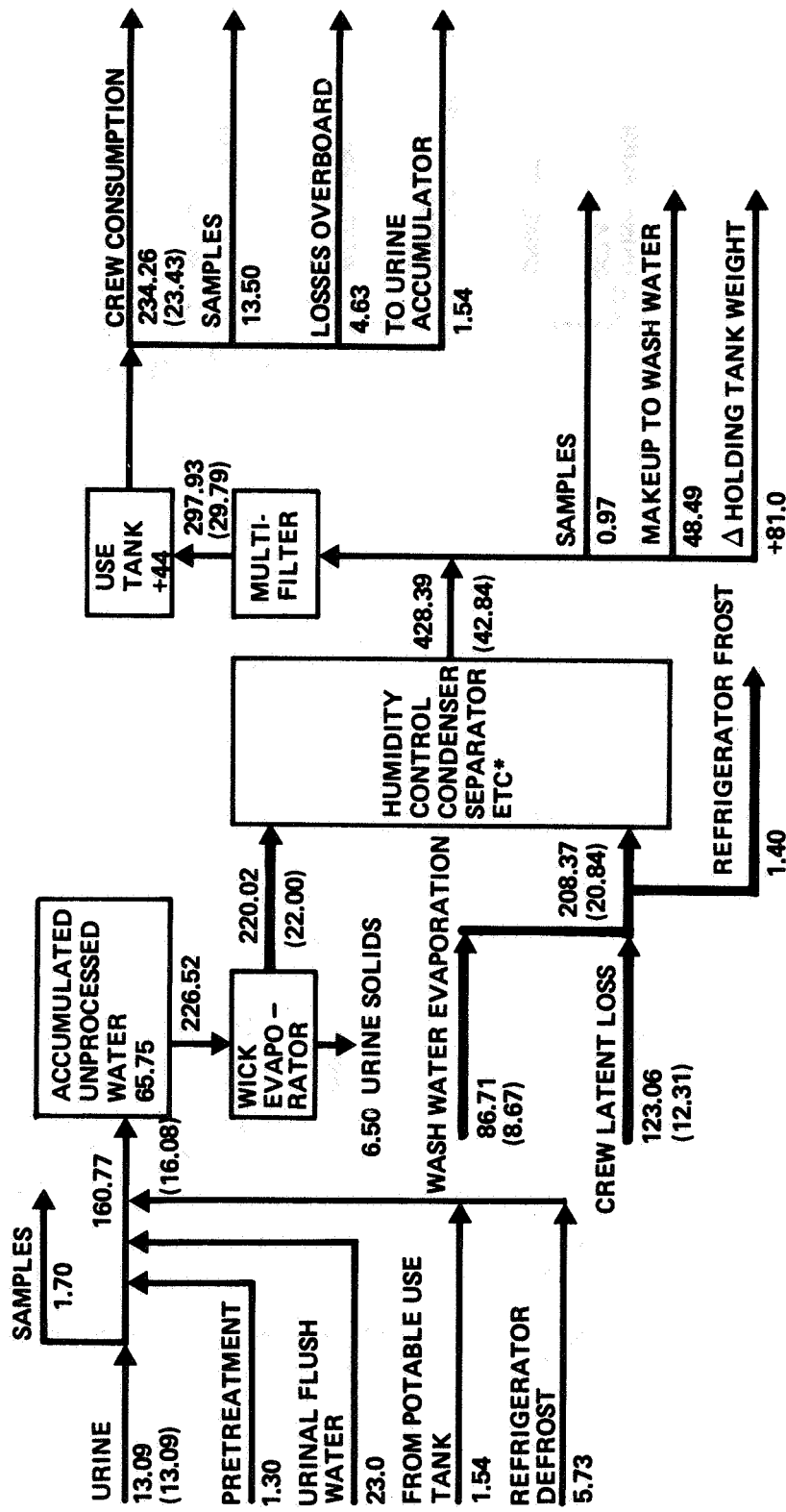


- WICK EVAPORATOR ON LINE
- SOLID AMINE UNIT ON LINE
- NO VD-VF OPEARTION

Figure 3

POTABLE WATER SYSTEM MASS BALANCE

TEST DAY 81 THROUGH 90 (10 DAYS)



*NOTE: ALSO INCLUDES SEPARATOR OVERFLOW AND CONDENSATE FROM SILICA GEL DESORBATE AND THERMAL CONTROL

- WICK EVAPORATOR ON LINE
- MOLECULAR SIEVE CO₂ CONCENTRATOR ON LINE
- NO VD-VF OR SOLID AMINE UNIT OPERATION

Figure 4

WASH WATER MASS BALANCE

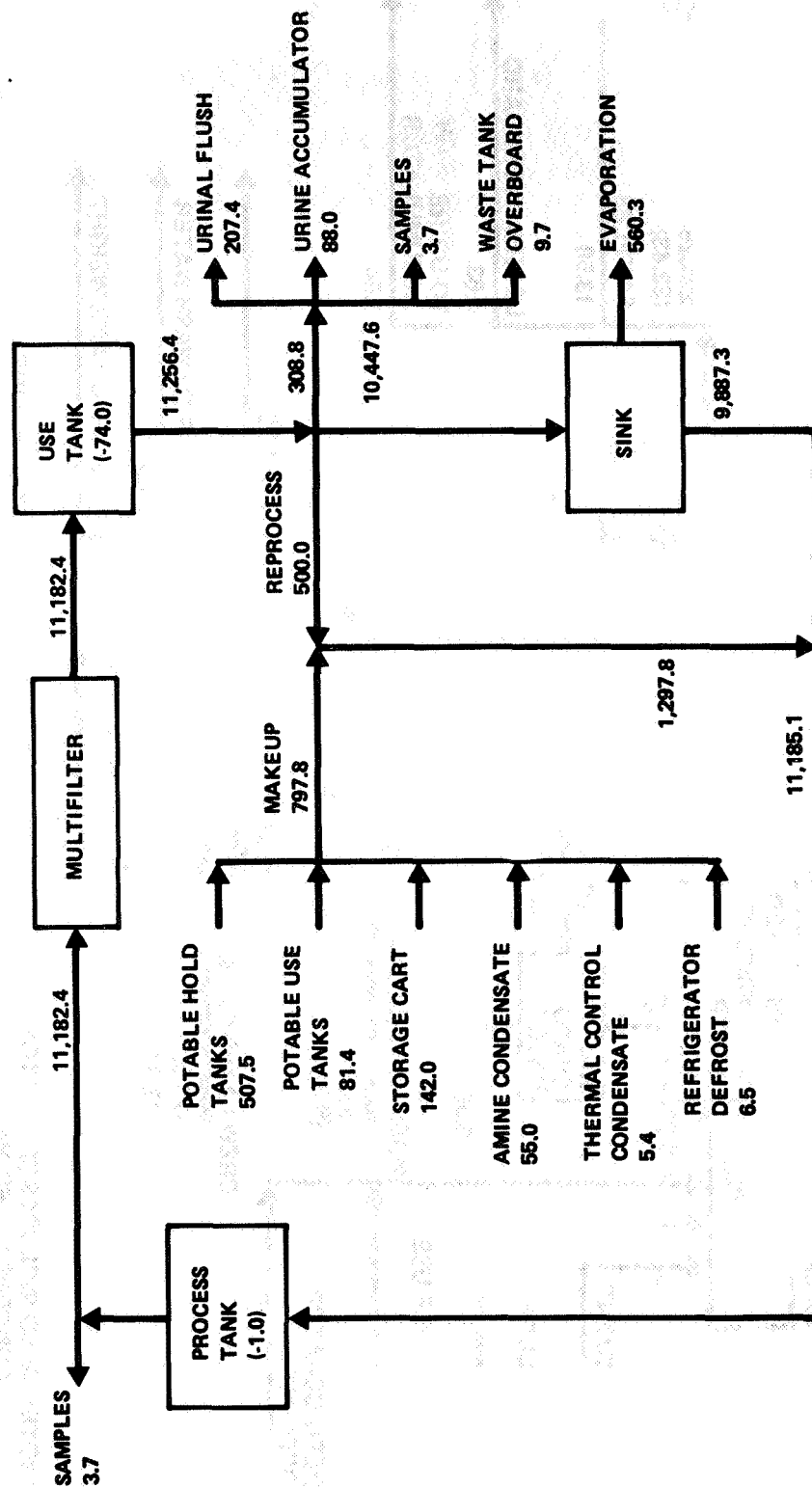


Figure 5

ATMOSPHERIC GAS MASS BALANCE

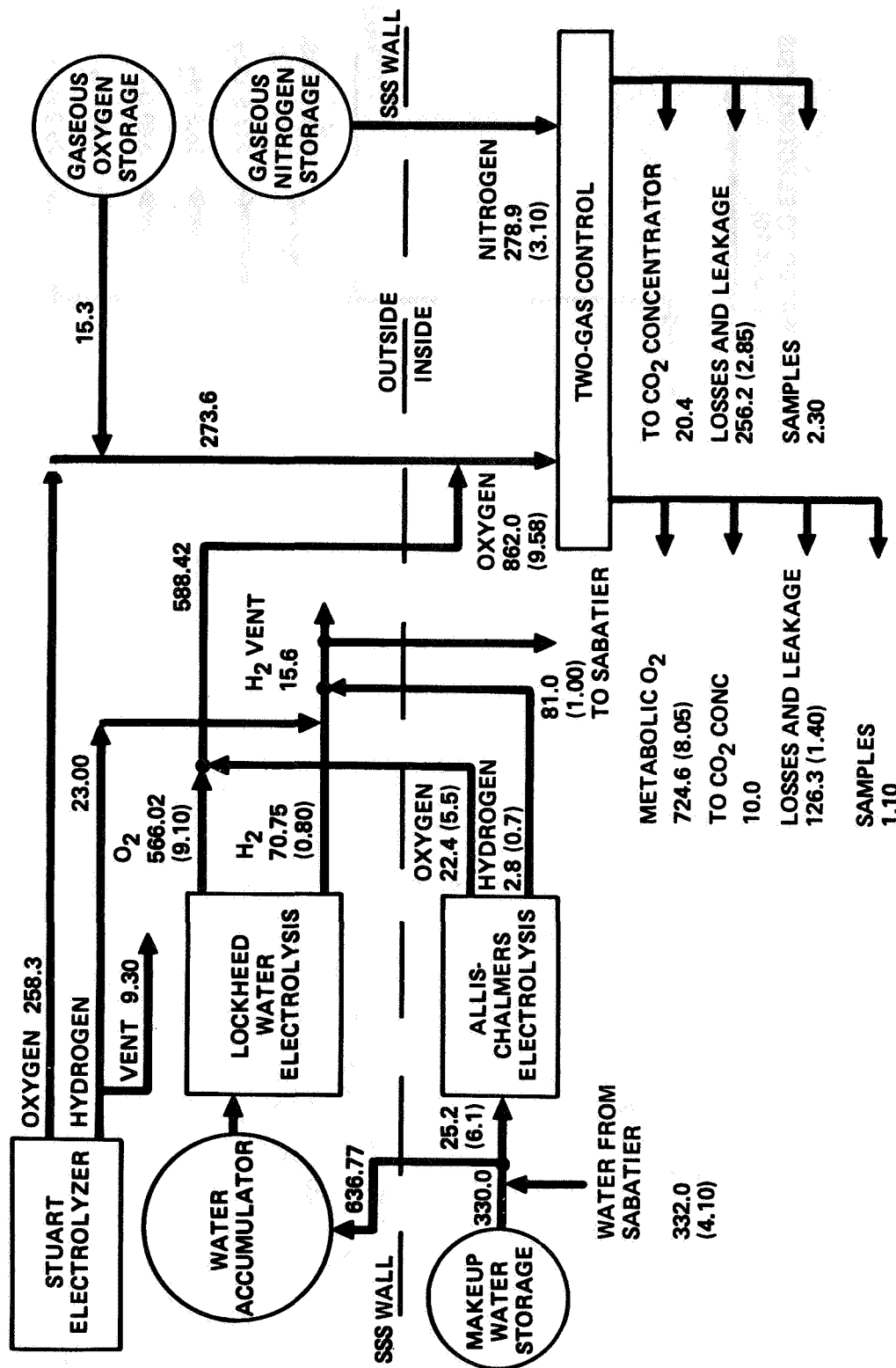


Figure 6

ATMOSPHERE RECOVERY MASS BALANCE

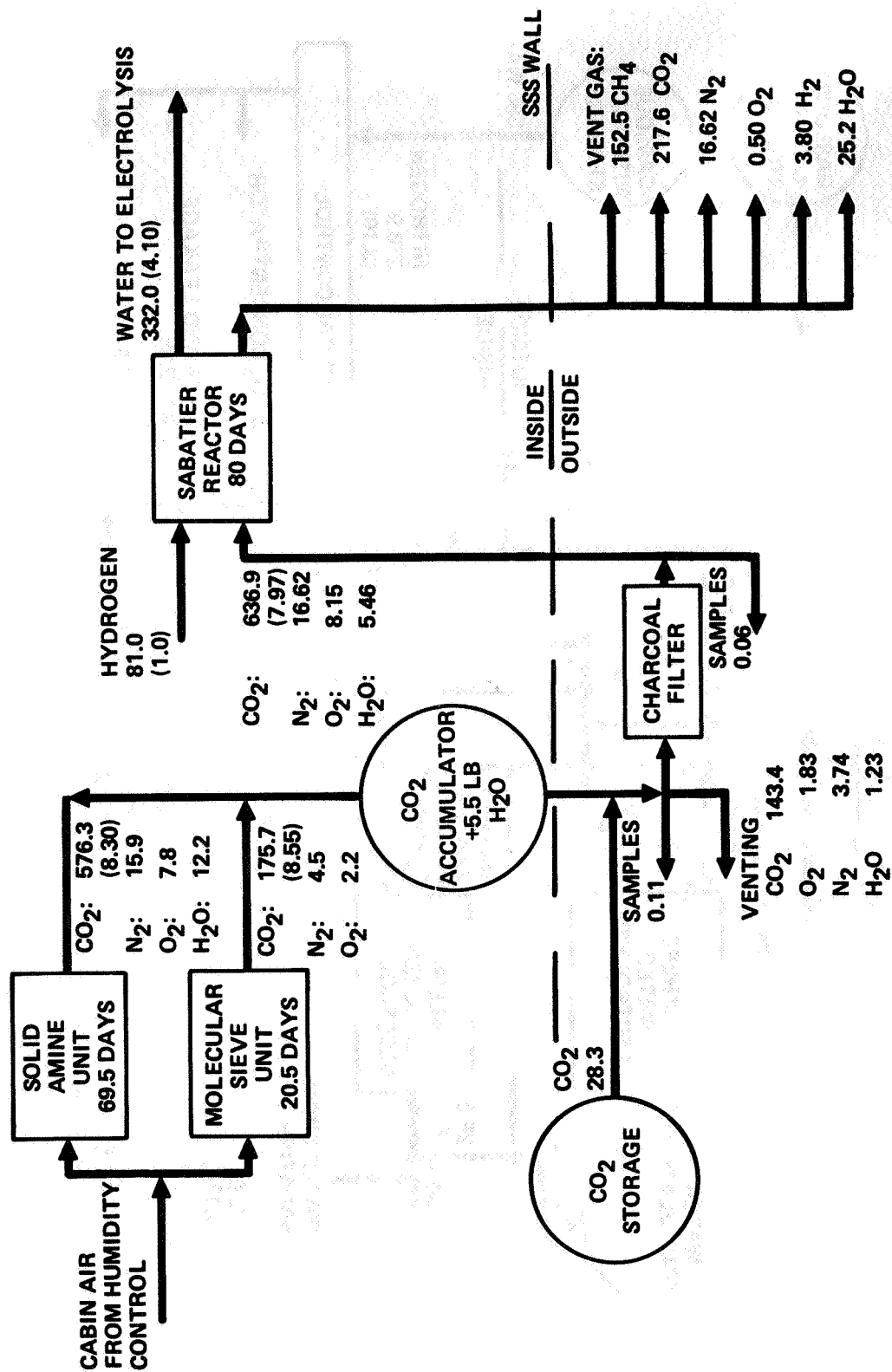
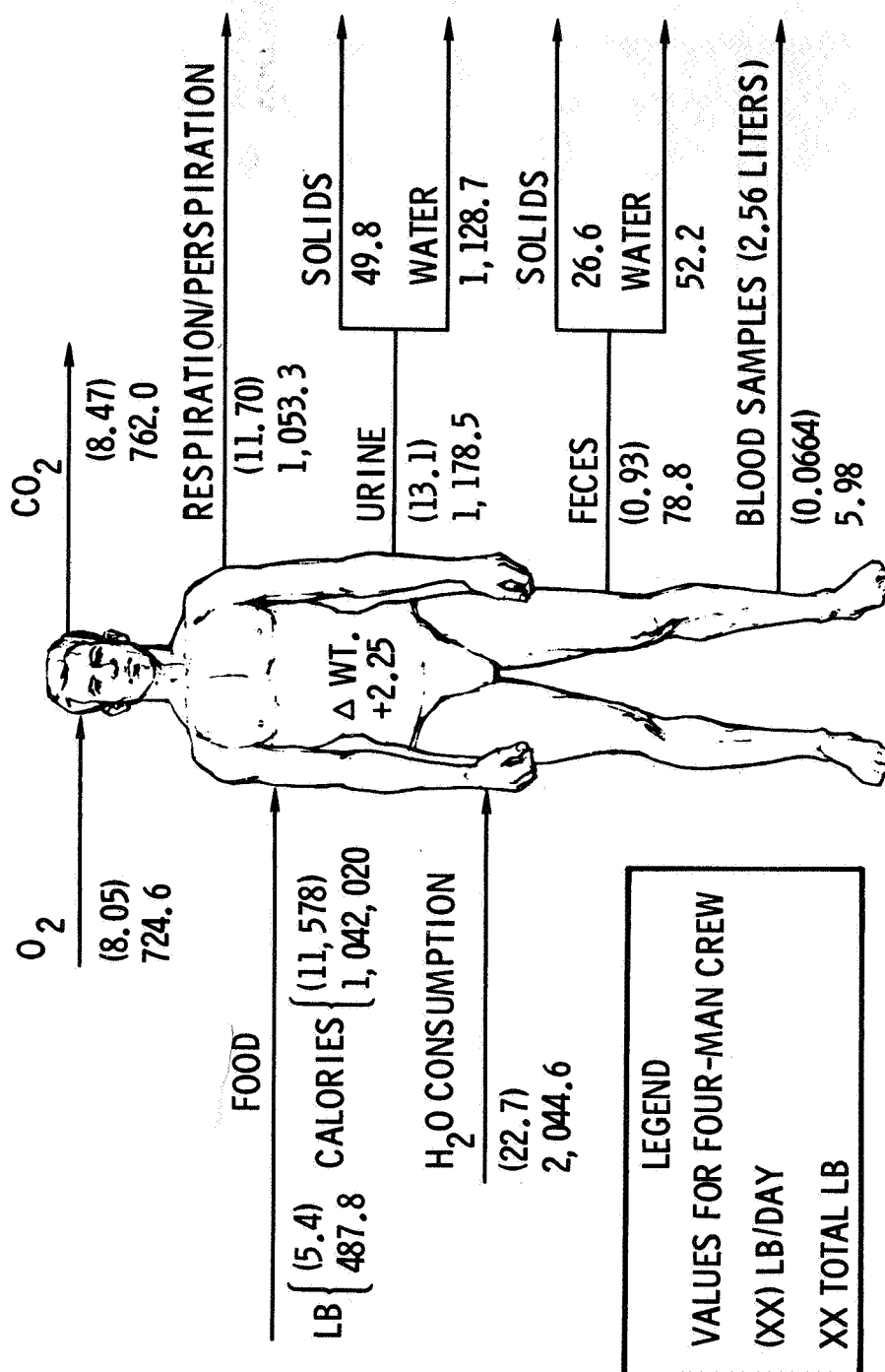


Figure 7

AVERAGE CREW INPUT / OUTPUT DATA



THERMAL BALANCE DATA

By J. K. Jackson and G. E. Allen

McDonnell Douglas Astronautics Company

SUMMARY

Thermal conditioning of the Space Station Simulator (SSS) during the 90-day test was done by a cooling loop circulating Coolanol 35 at 32 to 40°F. Process heating fluid was also provided by a circulating loop using electrically heated Coolanol 35. This loop supplied the carbon dioxide concentrators: the solid amine unit at about 240°F and the molecular sieve unit at 320°F. Total heat removed from the chamber varied from 22,846 Btu/hr (6.695 kW) to 29,514 Btu/hr (8.650 kW), depending on operating mode of the life support units. This total does not include thermal control requirements for water electrolysis, because operating time on the Allis-Chalmers unit was too short to reach equilibrium and the Lockheed unit was installed outside the SSS and separately cooled.

INTRODUCTION

The design of the thermal control subsystem is presented in paper number 7. To review, coolant is provided from external dual redundant refrigeration units that simulate a space radiator. The coolant, which is Coolanol 35, is supplied at 32 to 40°F at about 14 gpm. Coolant is supplied to a number of the life support units within the chamber to remove the heat generated and is also used for atmospheric cooling in the thermal conditioning unit to pick up all heat rejected to the atmosphere. The SSS is insulated to reduce heat transfer, and is operated at a temperature very close to the outside environment. It is estimated that heat transfer between the SSS and outside was less than 1,000 Btu/hr under any operating mode.

Process heating fluid, which is also Coolanol 35, is furnished to the chamber from an external, electrically heated reservoir. This fluid was used either by the solid amine or the molecular sieve CO₂ concentrator. Original plans for the SSS also included a Coolanol heated oven, but this unit was eliminated before the test because of possible material incompatibility. As the molecular sieve and solid amine systems were not required to operate simultaneously, the proper circuit temperature was achieved by setting the heater thermostat at the reservoir. This was approximately 240°F (115°C) for the solid amine unit and 320°F (160°C) for the molecular sieve unit.

The thermal balance includes all equipment normally operating inside the SSS. However, the Allis-Chalmers water electrolysis unit performed normally only during the first two days of the test. Adequate data are not available to determine its performance. The backup water electrolysis unit, built by Lockheed Aircraft Corporation, was installed outside the SSS due to lack of available internal space. It was provided with a separate coolant source. No thermal performance data were obtained on this unit.

SYSTEM DESCRIPTION

Equipment which must be considered in the thermal balance is listed in table 1. This shows the major heat producing and removal equipment. Although some condensation did occur in thermal conditioning unit, this amounted to less than 3 percent of the maximum total latent load. Condensation also occurred in the solid amine unit, although this was rarely enough to remove all the water vapor introduced in the steam desorption of the beds. Condensation in the silica gel bed desorbing air stream of the molecular sieve assisted in reducing the cabin humidity. Condensation that occurred in the Sabatier reactor exhaust and VD-VF vent gas did not influence the cabin latent load since these exhaust products were vented to overboard vacuum.

SYSTEM PERFORMANCE

The thermal balance was subject to considerable changes from day to day as the operating modes of the various life support units were changed. Chief among these variations were the following:

- A. When the wick evaporator was processing urine, an electrical air preheater was used, adding about 1,020 Btu/hr (300 watts) to the heat input to the unit.
- B. When the VD-VF unit was not operating, heat generation by the Pu-238 radioisotope capsules was removed in a storage chamber cooled by the coolant fluid loop.
- C. Large changes in thermal inputs occurred, depending on use of the solid amine or molecular sieve units for CO₂ removal.
- D. Changes in latent load from the washer and dryer resulted from variations in the laundry operations.

In order to describe system operations with these variations included, data is presented in figures 1 through 4 representing unit operating modes for four typical days of the mission. These are as follows:

Figure 1, Day 23: Molecular sieve and VD-VF operating, solid amine not operating, wick evaporator preheater not operating.

Figure 2, Day 50: Solid amine unit and wick evaporator preheater operating; molecular sieve and VD-VF not operating.

Figure 3, Day 58: Solid amine unit and VD-VF operating.

Figure 4, Day 83: Molecular sieve unit and wick evaporator operating.

Although these represent typical days, data presented for each unit generally represent averages over much longer periods of time. The crew sensible and latent loads are averages for the entire mission, and were derived from caloric values of food intake, net weight change, and respiration/perspiration values from the water recovery mass balance data. Values for the molecular sieve and solid amine units represent averages over significant periods of apparently normal operations.

TABLE 1
LIFE SUPPORT EQUIPMENT
INVOLVED IN THERMAL BALANCE

EQUIPMENT	HEAT PRODUCING			HEAT REMOVAL	
	ELECTRICAL	LATENT	SENSIBLE	LATENT	SENSIBLE
CO ₂ REMOVAL					
SOLID AMINE UNIT	X	X	X		
MOLECULAR SIEVE UNIT	X		X	X	
SABATIER/TOXIN	X	*	X	*	
POTABLE WATER RECOVERY					
VD-VF	X	*	X	*	
AIR EVAPORATOR/HUMIDITY CONTROL	X			X	X
LIGHTING AND RECREATION	X				
CREWMEN	X				
MISCELLANEOUS, INCLUDING:					
WASH AND POTABLE WATER STORAGE		X	X		
REFRIGERATOR AND FREEZER					
HOT PROCESS FLUID LINE LOSS					
EXPERIMENTS					
MISCELLANEOUS UNITS				**	
THERMAL CONDITIONING UNIT	X			**	X

NOTES: * LATENT HEAT PRODUCTION WAS REMOVED BY CONDENSERS WITHIN UNITS.

** LATENT HEAT REMOVAL BY THERMAL CONDITIONING UNIT WAS LESS THAN 3% OF THE
 MAXIMUM TOTAL LATENT LOAD

OVERALL THERMAL BALANCE TYPICAL FOR DAY 23

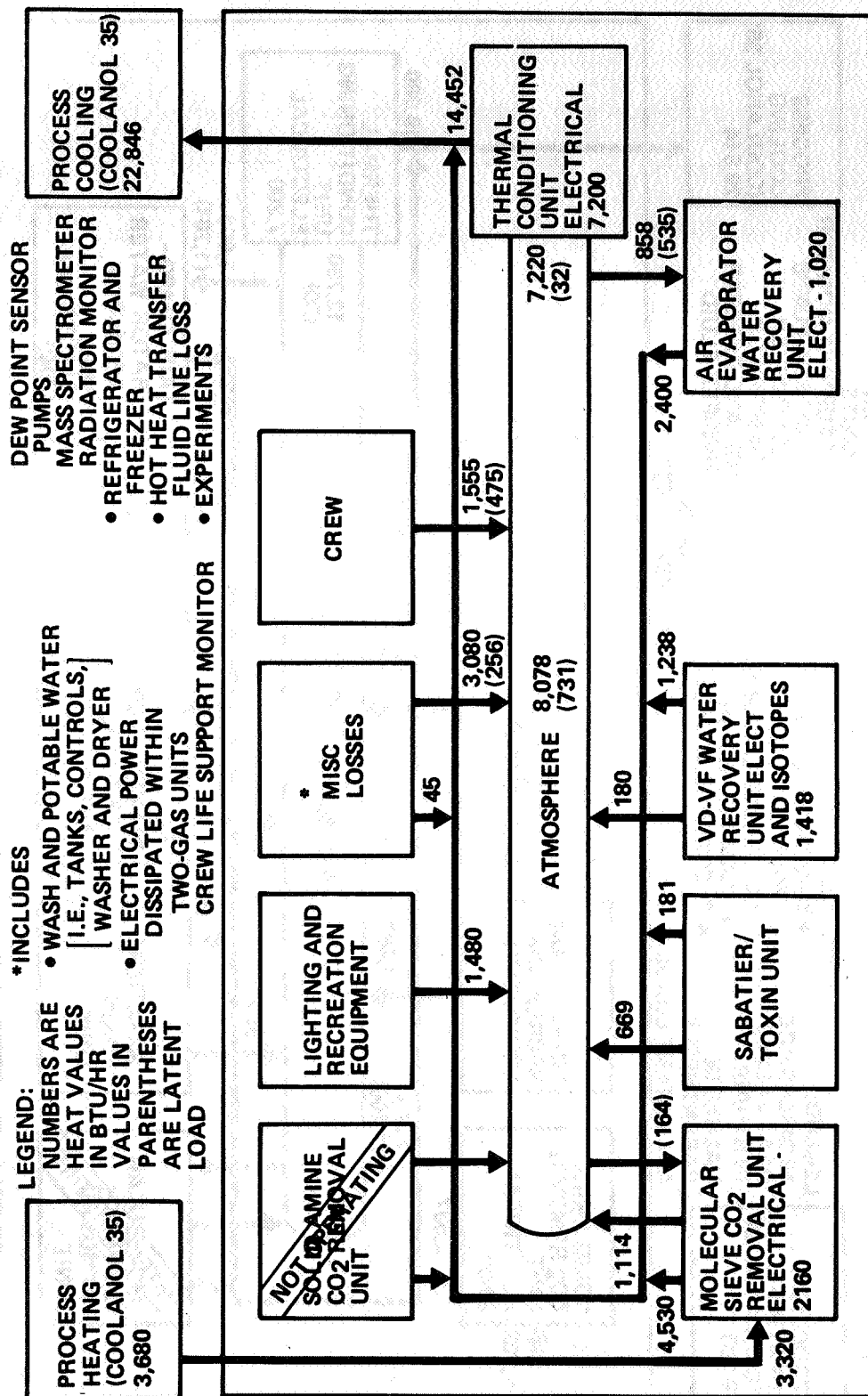


Figure 1

OVERALL THERMAL BALANCE TYPICAL FOR DAY 50

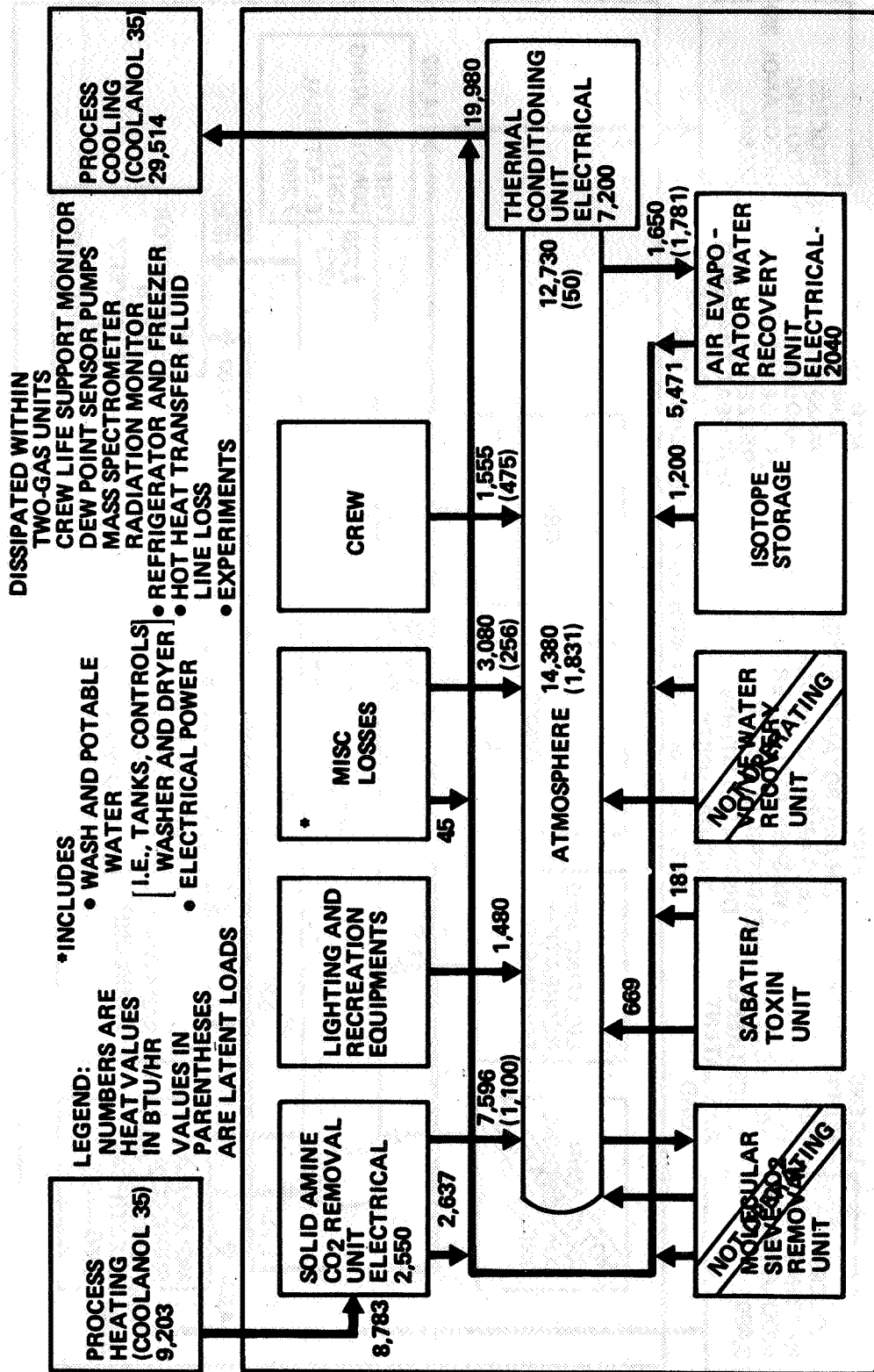


Figure 2

OVERALL THERMAL BALANCE TYPICAL FOR DAY 58

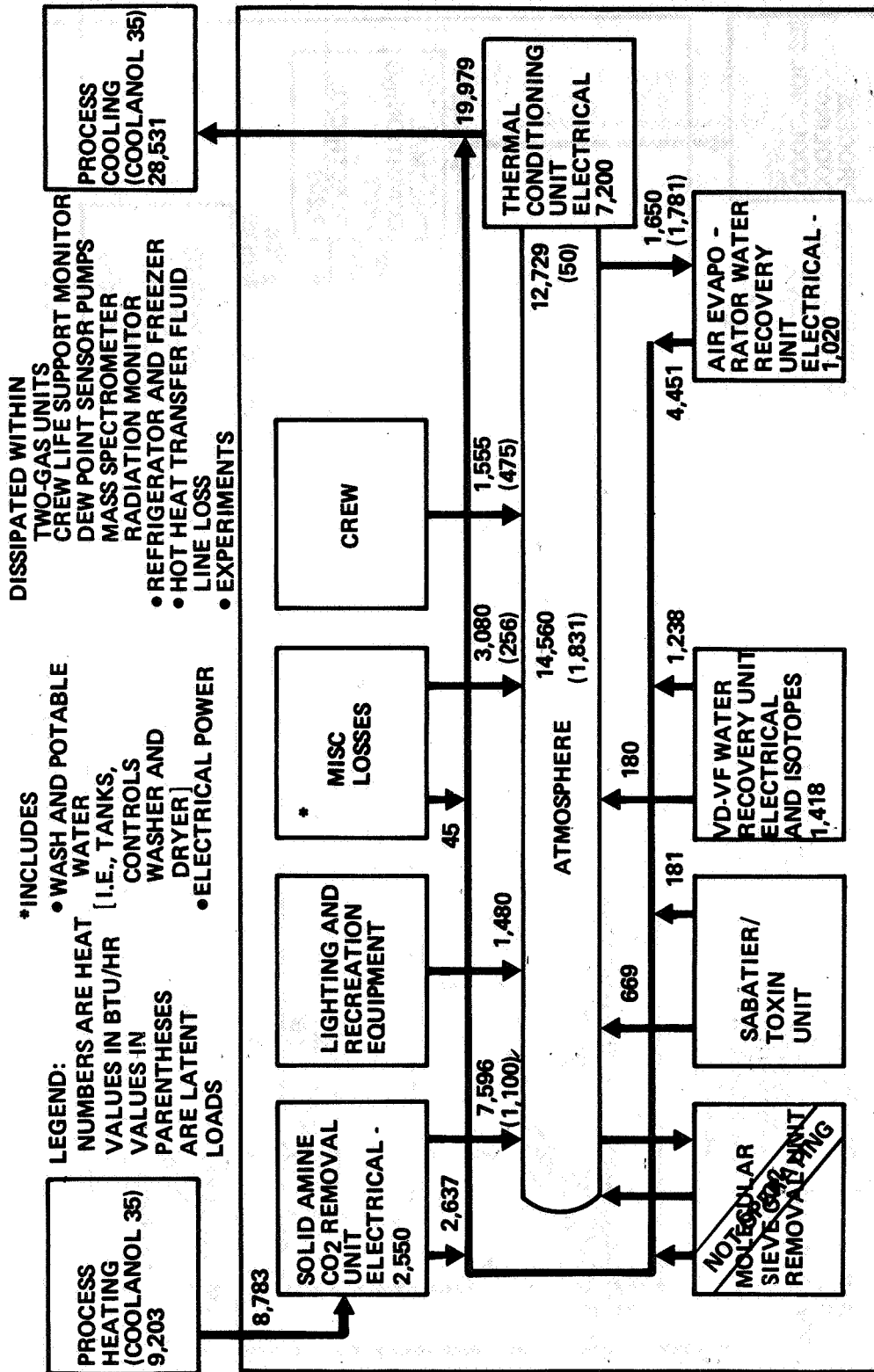


Figure 3

OVERALL THERMAL BALANCE TYPICAL FOR DAY 83

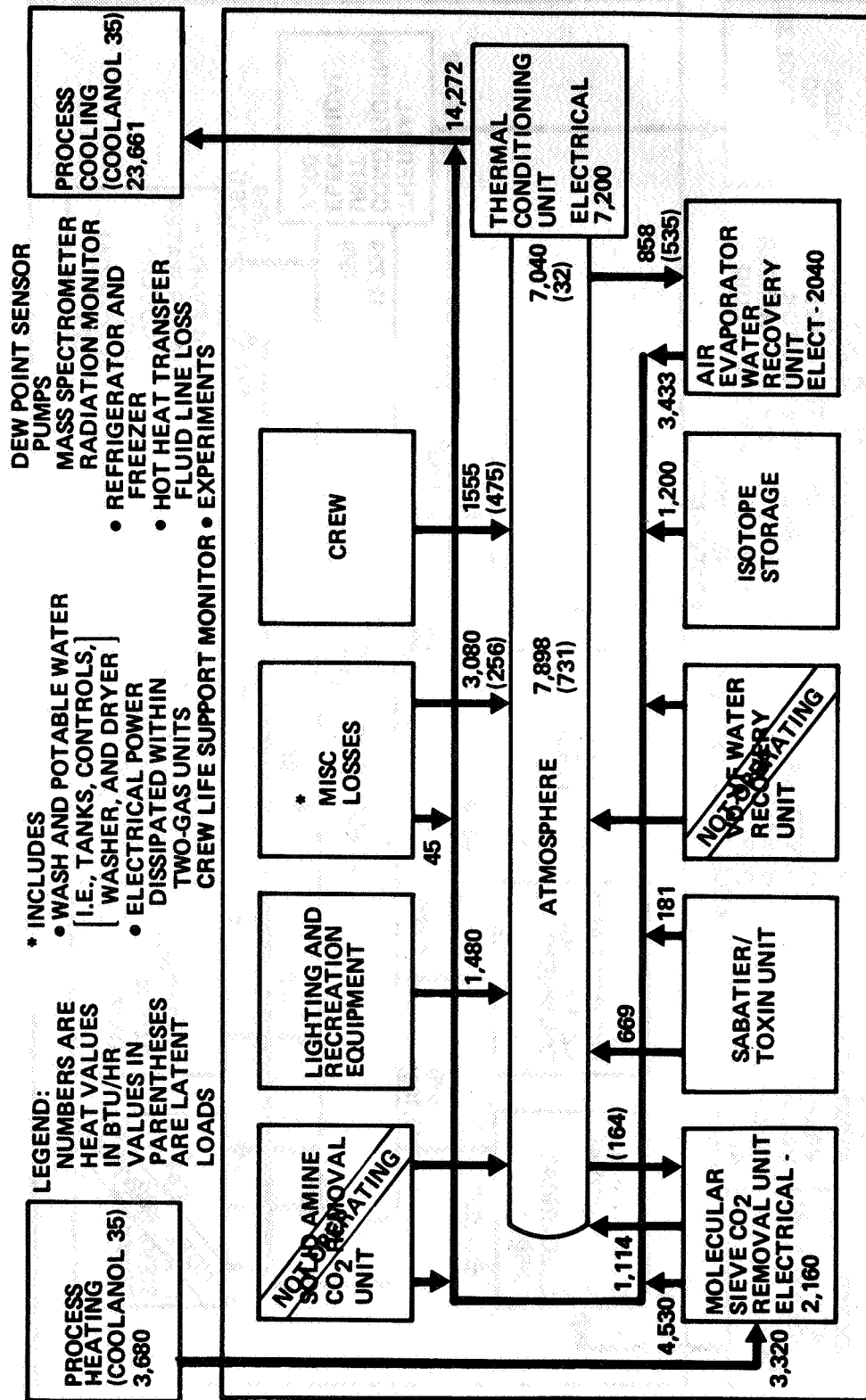


Figure 4

ELECTRICAL POWER DISTRIBUTION AND USAGE

By J. K. Jackson and N. A. Jones

McDonnell Douglas Astronautics Company

SUMMARY

The electrical power subsystem for the 90-day test included 60 Hz, 115 Vac, 1 phase; 400 Hz, 120/208 Vac, 3 phases; and 28 Vdc. Power usage was recorded by watt-hour meters on each 60-Hz circuit, watt meters on each 400-Hz circuit, and ammeters and voltmeters on the dc circuits. Automatic recording of power data was provided by six power sensors on groups of the ac circuits and a shunt in the dc circuits. These signals were recorded on the low-speed data system (LSDS).

Electrical energy usage was 8,169 kWh on the 60-Hz circuits, 5,885 kWh on the 400-Hz circuits, and 2,257 kWh on the dc circuits. The total energy was 16,012 kWh, for an average power consumption of 7,425 watts. Power and energy requirements of each unit are presented.

INTRODUCTION

The power distribution system for the Space Station Simulator (SSS) was designed to meet all industrial code requirements. As a result, a large number of circuits were provided and many of these were very lightly loaded. Further requirements were established during the safety reviews which included insurance that each circuit wire gage was adequate for the circuit breaker protection provided and that each using element was fused to prevent destructive currents. An example of the latter was the provision of individual fuses on electric motors that were selected to protect against locked rotor current values.

Instrumentation was provided to establish average and instantaneous power readings. Insofar as possible, this instrumentation was intended to show the power requirement for each unit, but constraints on circuit arrangement and the numbers of available instruments prevented full achievement of this objective.

In designing and operating the life support system, efficient design from a power requirement standpoint was a secondary objective. In many cases, inefficient components were selected for economic reasons. Similarly, no effort was made to schedule operation of intermittent equipment to influence the occurrence of power-load peaks.

SUBSYSTEM DESCRIPTION

The electrical hardware incorporated into the SSS was designed to use one or more of the following power forms; 115 Vac, 60 Hz, single phase; 120/208 Vac, 400 Hz, three phase; and 28 Vdc.

Twenty 115-Vac, 60-Hz circuits were utilized with 20-amp circuit protection in each circuit. Table 1 shows these circuit allocations. One 120/208-Vac, 400-Hz circuit was employed with a maximum circuit capacity of 50 amps with individual breakers on each unit. Table 1 indicates circuit allocations for this power. Two 28-Vdc circuits of 60 amps each were utilized to supply 28-Vdc power to the SSS/LSS. An additional onboard 28-Vdc power distribution panel was incorporated for more efficient distribution of the 28-Vdc power. A third 28-Vdc power circuit provided power for the test control area.

Backup power supplies were connected in parallel with the primary 28-Vdc and the 400-Hz motor generator to allow fast manual switchover if necessitated by loss of the primary supply or need for preventive maintenance.

An emergency backup 28-Vdc supply was incorporated into the overall electrical power system to automatically activate should the facility 115-Vac, 60-Hz power fail. The emergency power supply consisted of a battery pack which, when activated, provided power to the emergency power bus for emergency onboard lighting and control of all safety-oriented chamber control functions. The emergency battery pack was maintained at full voltage with a trickle charger when not on line.

The electrical power distribution system incorporated relay isolation of all electrical power entering the chamber with the exception of intercom, television camera power and emergency lighting circuits which were classified as essential for safety of the crew. The electrical isolation circuits were integrated into the automatic abort sequence. The power system block diagram is shown on figure 1. Seven power sensors, also shown in figure 1, were used for measuring power on groups of circuits as shown on table 1 and figure 1. These sensors provided a millivolt signal proportional to actual power for the ac circuits. A shunt was used in the dc circuit, with power being computed using the nominal 28-V terminal voltage. All millivolt signals were recorded by the low-speed data system.

SUBSYSTEM PERFORMANCE

The SSS power subsystem experienced two major facility 115-Vac, 60-Hz power failures, the longest lasting approximately 20 sec. The major power events are shown in table 2. The power failure produced no problems with the onboard or facility support equipment, but required restarting the affected systems. The emergency backup 28-Vdc activated properly and provided the required SSS lighting and chamber control power. The backup 400-Hz motor generator was used on days 66 and 67 to facilitate preventive maintenance on the primary motor generator drive belt.

The average power consumed during the 90-day run is diagrammed in figure 2. The detailed subsystem power consumption and total power for the 90-day run are itemized in tables 3 and 4.

Power consumption for the run was derived from commercial watt-hour meters as shown in figure 1 identified by WHR prefix. Additional power instrumentation was incorporated into the SSS power lines to allow real-time recording of instantaneous power on all lines entering the chamber. The real-time power instrumentation is shown in figure 1 with identification prefix of WIR.

Three power profiles were made during the run on days 38, 67, and 79. Samples were taken and recorded on the low-speed data system every 4 minutes for each of the three 24-hour periods. Figures 3 through 8 show the resulting power profile for the ac power circuits on the 67th test day.

Power provided to the Lockheed electrolysis unit which was located outside the SSS was not included in the SSS power instrumentation system. During the run, the following power was provided the Lockheed electrolysis unit while it was on line and supplying gas to the SSS:

300 MA	120/208 Vac, 3 phase, 400 Hz (3 sec on, 15 min off)
2.5 Amp	115 Vac, 1 phase, 60 Hz for controls and the oxygen compressor
1,300 Watts	DC on high mode operation, 1,349.1 hr
445 Watts	DC on low mode operation, 140.1 hr

Table 1
SSS EQUIPMENT POWER CIRCUITS

Meas. No.	Circuit	
WIR-DZ 115 Vac 60 Hz	A2	Refrigerator, clothes washer, waste management, electric oven * ⁿ Sabatier/Toxin, crew life support, dew point pump.
	A4	Airlock Controls, crew area lights.
	A6	Clothes dryer.
	A8	Air samplers (2), critical task testor, pass thru port controls, conductivity meter, T.V. monitor, solid amine air compressor.
WIR-D3 115 Vac 60 Hz	A1	Bed lights (2), T.V. monitor, vision testor, incubator, timer, deep freezer, radiation monitor.
	A3	Bed lights (2), portable nuclei counter, equipment area lights (4)
	A5	Dew point pump, bio-medical ergometer, VD-VF, mass spec. flight weight, two-gas pneumatics, base line 2-Gas.
	A7	Microwave Oven
WIR-D4 115 Vac 60 Hz	C2	Wash tank #8
	C4	Potable tank #3
	C6	Potable tank #5, water circulation pump.
	C8	Solid amine
WIR-D6 115 Vac 60 Hz	C1	Sink pump.
	C3	Wash tank #7, waste overboard pump.
	C5	Potable tank #1, wick evaporator air heater.
	C7	Potable tank #6, metering water pump.
WIR-D7 115 Vac 60 Hz	D2	Potable tank #2
	D4	Thermal control, nuclei counter air pump.
	D1	Potable tank #4, urine liquid level control
	D2	CO ₂ concentrator
WIR-D1 28 Vdc	B	Allis-Chalmers electrolysis, baseline and flight weight, two-gas Sabatier/Toxin, CO ₂ concentrator, crew life support, potable water dispenser, solid amine, waste management, wash water control, potable water control.
WIR-D5 120/20B Vac 3 phase 400 Hz	F	Lithium hydroxide*, CO ₂ concentrator, wick evaporator, commode, thermal control.

* Not used during 90-Day Test.

Table 2
SIGNIFICANT POWER SYSTEM EVENTS

Test Day	Time	Event
10	12:06	DC Power surge on all consoles, problem traced to a momentary short created by onboard crewman working on Allis-Chalmers electrolysis unit. Onboard DC breaker for unit tripped, reset breaker with no problem.
28	09:50	SSS 115-Vac. 60-Hz circuit A5 (20 amp) circuit breaker tripped due to short in VD-VF control wiring. Corrected short and reset breaker and performed a restart on mass spectrometer.
40	02:00	Facilities 115-Vac, 60-Hz power momentarily failed, lost coolanol system, solid amine and 400-Hz motor generator, perform restart on affected systems.
45	08:30	SSS 115-Vac. 60-Hz circuit A5 (20 amp) circuit breaker tripped due to short in VD-VF liquid level switch, corrected malfunction, reset breaker and performed a restart on mass spectrometer.
57	06:30	Facilities 115-Vac, 60-Hz power failure occurred for approximately 20 seconds, all onboard and SSS support systems went OFF, emergency SSS 28-Vdc battery power automatically came on to provide SSS lighting, maintained communication system via communication backup battery supply. Performed normal restart on all affected systems with no problem.
66	08:50	Switched to backup 400-Hz motor generator to perform preventive maintenance on drive belt of primary motor generator.
68	08:00	Switched back to primary 400-Hz motor generator.

Table 3
POWER REQUIREMENTS FOR SPACE STATION SIMULATOR
(60 Hz, 115 Vac, 1 ϕ)

Subsystem/Unit	Components	Energy Input kWh	Average Power WATTS*
Wash Water	2 Tank Heaters 2 Pumps	519.6	240.9
Potable Water	6 Tank Heaters Wick EUAP Preheater 2 Pumps	1564	725.2
Thermal Control	Circulating Pump Controls	2158	1000.7
Molecular Sieve (19 Days)	Vacuum Pump Controls	180	394.7
Solid Amine (72 Days)	-	1296	762.1
Water Electrolysis (62 Days)	Lockheed, O ₂ Compr.	428.1 Δ	287.5
Sabatier/Toxin Housekeeping	- Lighting, Biomed, Etc.	22 1631	10.2 756.3
2 Gas Control		70.7	32.8

NOTES: * All subsystems include small intermittent dc loads for controls.

Δ Lockheed water electrolysis unit installed outside SSS.
Power data includes estimated component efficiency for compressor.

Table 4

POWER REQUIREMENTS FOR SPACE STATION SIMULATOR
SUMMARY INCLUDING 400 Hz AND 28 Vdc

Power Source	Subsystem/Unit	Components	Energy Input kWh	Average Power WATTS *
120/208 Vac 400 Hz, 3 ϕ	Wick Evaporator	Blower (Humidity Control)	660.585	306.3
	Thermal Control	Blowers (2)	5,107.35	2,368.3
	Molecular Sieve (19 Days)	Blower	116.28	255.0
	Housekeeping	**		
	TOTAL		5,885.00	2,729.0
28 Vdc	Water Electrolysis	Allis-Chalmers (4 Days) Lockheed (62 Days) *	139.6	1,454.2
	Other Uses Inside Chamber		1,816.1 Δ	1,219.5
			301.7	139.9
	TOTAL		2,257.4	1,046.8
115 Vac 60 Hz, 1 ϕ	Total From Other Table		8,169.4	3,788.3
	TOTALS		16,011.8	7,424.9

NOTES: * All subsystems include small intermittent dc loads for controls.

** Housekeeping function includes intermittent 400 Hz power.

Δ Lockheed water electrolysis unit installed outside chamber unit required small intermittent 400 Hz power for water pump power data includes allowance for estimated efficiency of dc-dc converter.

POWER SYSTEM BLOCK DIAGRAM

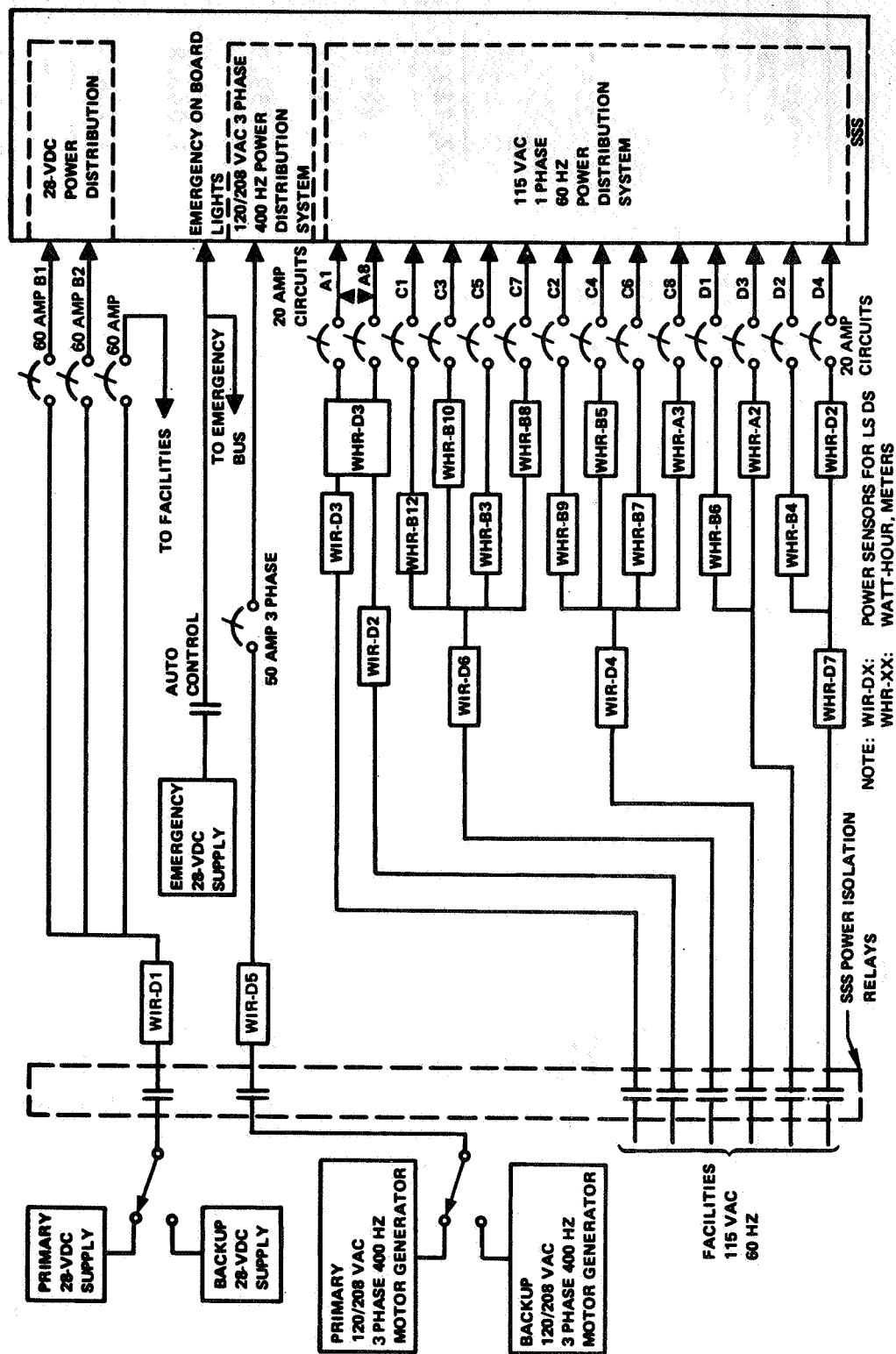


Figure 1

GENERAL SUMMARY OF POWER LOAD PROFILE

90-DAY TEST OF SSS

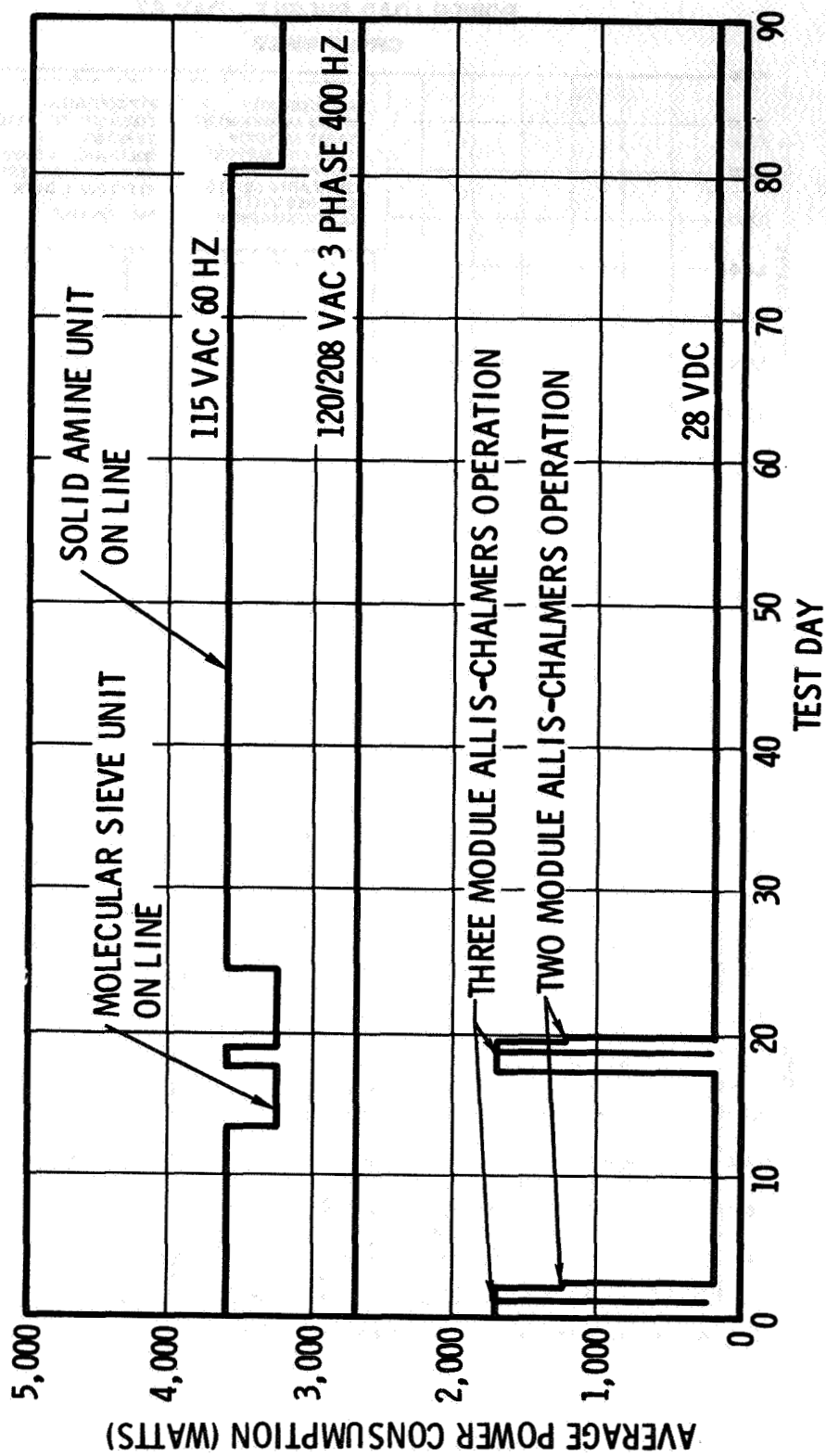


Figure 2

POWER LOAD PROFILE - DAY 67

CIRCUIT WIR-D2

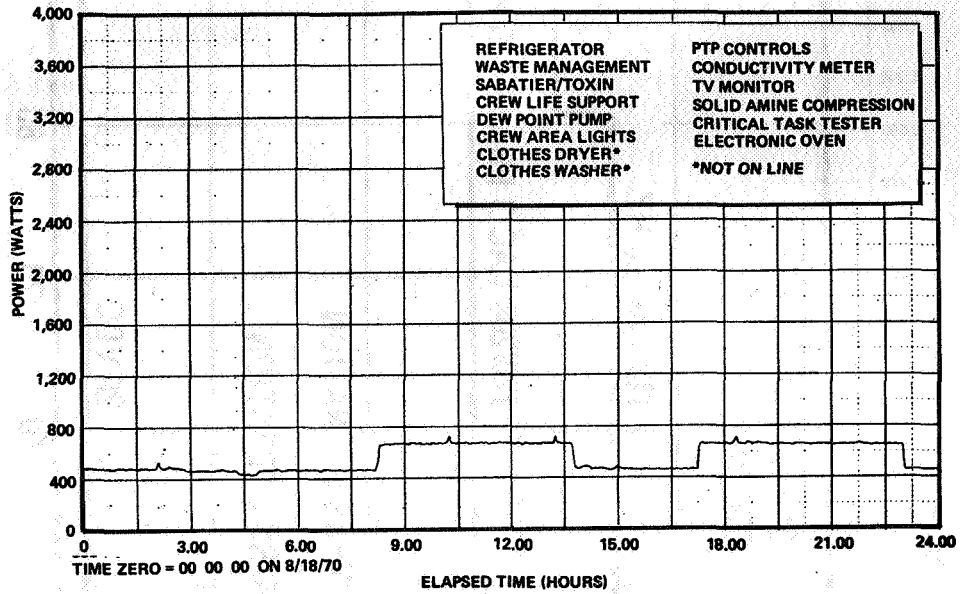


Figure 3

POWER LOAD PROFILE -- DAY 67

CIRCUIT WIR-D3

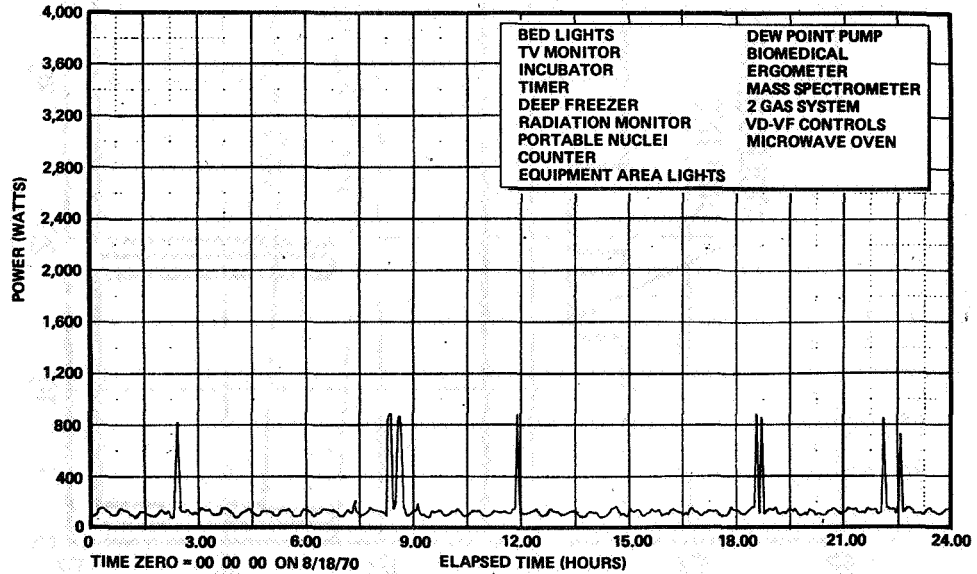


Figure 4

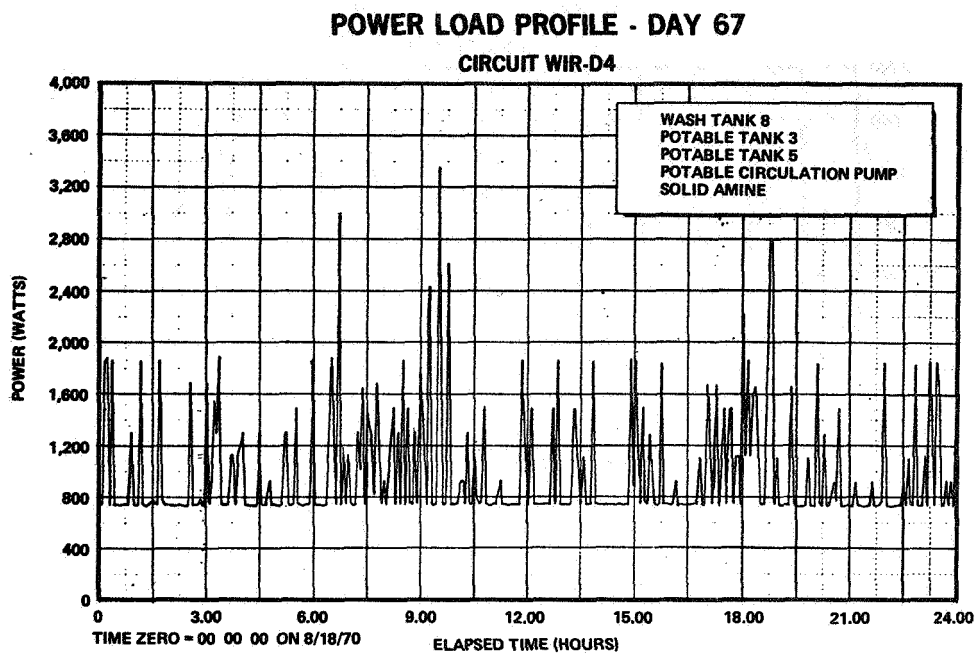


Figure 5

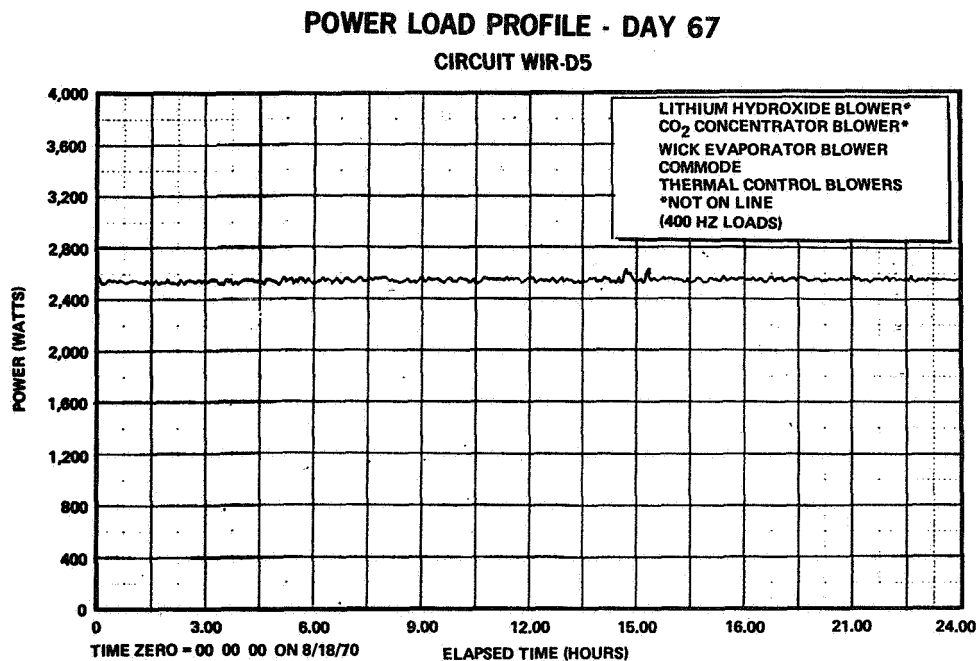


Figure 6

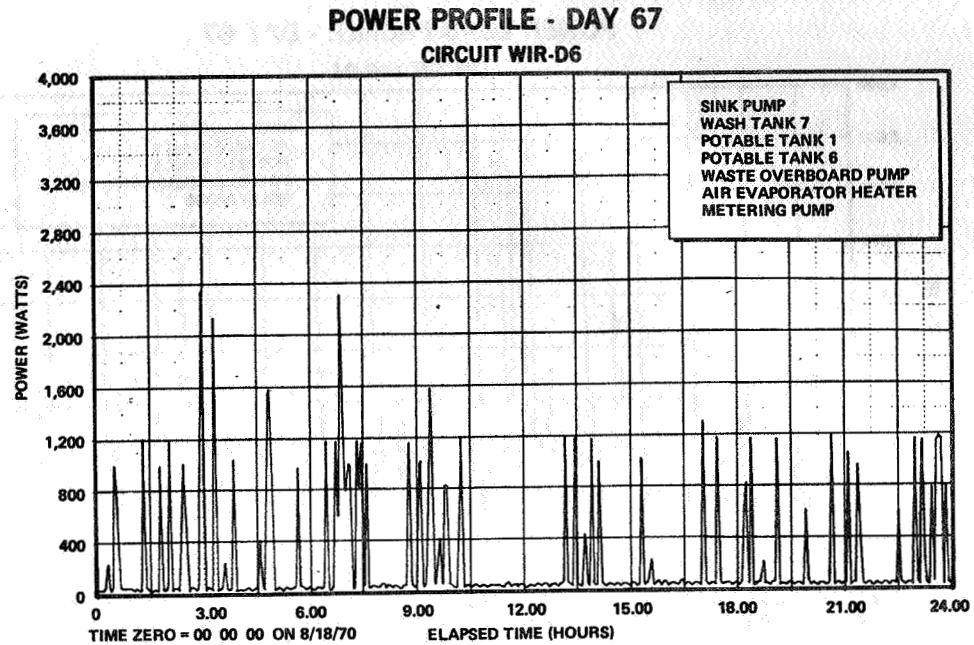


Figure 7

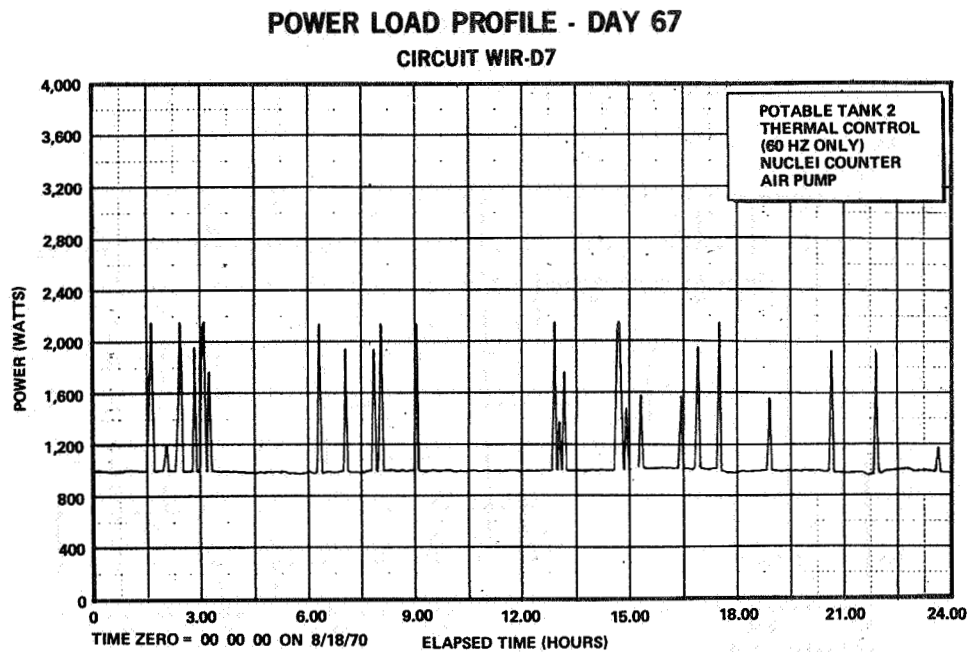


Figure 8

MAINTENANCE AND REPAIR REQUIREMENTS

By M. S. Bonura

McDonnell Douglas Astronautics Company

SUMMARY

A primary mission objective of the SSS 90-day manned test was that all spares would be stored onboard with all required maintenance and repair tasks performed by the crewmen. This mission objective was met since all maintenance and repairs were accomplished utilizing only onboard spares.

During the test, the crew performed 212 maintenance and repair tasks on the life support system (LSS) and over 40 maintenance and repair tasks on miscellaneous support equipment. The total crew time on the LSS was 117.4 hours for repair and 34.4 hours for maintenance. The total crew time for all maintenance and repair tasks was approximately 203 hours or 2.3 hours/day.

All LSS units were successfully repaired with the exception of the zero-g urine collector and the onboard Allis-Chalmers electrolysis unit. These units were shut down on days 6 and 20, respectively, when the onboard repair efforts could not restore operation. The test was completed using backup procedures and equipment for these functions.

INTRODUCTION

To ensure the successful completion of the 90-day test, extensive planning was required to determine the spares and maintenance actions necessary for continuous operation of the SSS equipment. The basis of this planning task was the failure mode, effects, and criticality analysis (FMECA). The results of the FMECA were used as inputs to a computer program which generated a spares inventory list which was then reviewed by the responsible subsystem engineers for commonality of spares and for practical levels of component replacement or repair. The maintenance procedures were then formulated and the tool requirements and storage volume delineated.

The test crew was required to monitor, maintain, and repair the life support equipment which was installed within the SSS. The only life support unit which was not installed within the SSS was an electrolysis unit which was developed for NASA by the Lockheed Missiles and Space Company. This advanced subsystem was provided as a backup to the onboard Allis-Chalmers electrolysis unit and, due to space and time limitations, was installed outside the SSS.

The approach to life support equipment repair and maintenance simulated that aboard a space station vehicle. The test crew was trained to complete

normal repairs, maintenance, and part replacement. Standby procedures and units were provided and used until repairs could be completed on the primary unit. All repairs and maintenance on inside equipment was accomplished by the test crew utilizing the onboard spares. Verbal assistance, when required, was provided by the outside staff.

DISCUSSION

The reliability of the equipment was generally very good. The only major failures occurred with the onboard electrolysis unit and the zero-g urine collector. A summary of the life support system (LSS) operation during the 90-day test is shown in figure 1. The nonoperational periods for the wick evaporator, molecular sieve concentrator, toxin control, mass spectrometer, and baseline O₂ control sensor do not signify failure but periods when operation was not required and these units were in standby. A summary of LSS operating history is shown in figure 2.

The major failures which caused unit downtime are as follows:

- A. Urine Collector—On day 6, the phase separator failed because of addition of excessive urine pretreatment which severely damaged the separator impeller. The crew modified the unit for one-g operation.
- B. VD-VF—Between days 27 and 33, a malfunctioning boiler liquid-level control was repaired and the catalyst, which had been flooded with urine, was washed. On day 39 the condensate tanks, which had been micro-biologically contaminated by the flooding, were sterilized. Between days 45 and 52, the catalyst was again washed and the unit sterilized after a malfunction of the urine accumulator liquid-level control. On day 81, the unit was shut down when the second boiler was expended.
- C. Solid Amine Concentrator—Between days 14 and 17 unsuccessful attempts were made to repair a faulty bed selector valve. The unit was returned to operation on the remaining two beds. Between days 20 and 25, the unit was shut down to evaluate lack of CO₂ removal efficiency. Data evaluation revealed that the temperature reference junction had drifted 15°F and required recalibration. On day 34 the pneumatic compressor, which supplied control power, failed and was replaced by a nitrogen pressure line from the two-gas control supply source. On day 81 the unit was shut down when acceptable CO₂ levels could not be maintained in the SSS.
- D. Sabatier Reactor—Between days 14 and 16 the unit was in standby for evaluation of a suspected gas contamination problem. Nitrogen had been detected in the H₂ and Freon had been detected in the CO₂. Between days 17 and 27 the operation was intermittent with 25 shutdowns and restarts. On days 28 and 29 the catalyst was replaced. On day 59 the unit was in standby resulting from a lack of H₂ and available crewtime for restart. On day 81 a failed zero-g condenser separator was replaced.

- E. Allis-Chalmers Electrolysis—Between days 3 and 17 a failed module was replaced and all modules flushed. In addition, repairs were completed on the electronic control and a N₂ pressure regulator. Between days 18 and 20 the operation was intermittent and final failure occurred on day 20.
- F. LMSC Electrolysis—Between days 1 and 3 the unit was in standby. On day 4 a H₂ leak in module 1 was repaired. On day 9 operation was intermittent because repeated shutdowns of the 28-Vdc power supply. Between days 12 and 17 the unit was shut down to replace defective N₂ purge solenoid valves and the 28-Vdc power supply. Between days 18 and 21 the unit was in standby. Between days 45 and 48 the unit was shut down to repair a short in module 1, to repair leaks in modules 2 and 3, and to replace defective temperature switches. On day 60 a defective N₂ solenoid valve was repaired and the 28-Vdc logic power supply was replaced. Between days 63 and 66 module 2 was rebuilt. Between days 73 and 74 modules 1, 3, and 4 were rebuilt.

The LSS repair operations requiring hardware removal, repair, and replacement during the 90-day test are outlined in figure 3. The crew was also required to perform maintenance on equipment and the maintenance items which directly affected the LSS are also noted in figure 3. The hours noted are the best information obtainable from the test logs maintained by outside staff and crewmen.

Since the LMSC electrolysis unit was located outside the SSS, all 16 repair operations on this unit were performed by outside personnel. In addition, certain failures, which occurred in external gas sample and vent lines, were repaired by outside personnel. These items were the replacement of a flow transducer, the installation of a charcoal trap, and five charcoal changes in the Sabatier CO₂ sample loop, the draining of water from the Sabatier methane vent pump, and the replacement of the O₂ purifier in the electrolysis sample loop. These outside activities covered 25 items in 90.2 hours. Therefore, there were 152 onboard repair items which required 117.4 hours of crew time.

In addition to repair and maintenance of the LSS, the crew performed additional tasks on onboard experiments and other support equipment. The significant items are outlined in figure 4. Not included in figure 4 is the scheduled maintenance which was required for items such as the TV cameras, radiation monitor, and aerosol particle counters. This scheduled maintenance was estimated to be a total of approximately 23 hours. Therefore, the total onboard crew time for all maintenance and repair activities was approximately 203 hours or 2.3 hours/day.

As previously noted, all spares for the LSS and critical support equipment were stored onboard the SSS. The location and quantity were documented in the spares inventory list. There were 365 major items included in the spares inventory, not including items such as fluid fittings, wire, tubing, tape, and sealant. The usage of these major spare parts is noted in figure 5 and amounted to 14.3 percent usage of available spares.

CONCLUDING REMARKS

The performance of the equipment was very good considering the system complexity and the extensive use of nonflight-qualified prototype equipment. The performance of the crew was excellent in completing the many repair and maintenance tasks.

The stocked spares were sufficient to support the 90-day test except for those required for the urine collector and the Allis-Chalmers electrolysis unit. The use of the zero-g features of the urine collector were lost when the phase separator impeller was severely damaged on day 6. Unfortunately, this type of failure had not been anticipated by the FMECA and adequate spares were not available. Although two spare modules were provided for the Allis-Chalmers electrolysis unit, both spares were expended by day 20 and subsequent failures terminated the operation of this unit.

The lack of adequate spares for these two units only emphasizes the importance of adequate reliability data. Analysis such as the FMECA is only as good as the available data. On new prototype equipment, this can only be obtained by extensive bench testing and long-duration tests such as the 90-day test.

LIFE SUPPORT UNIT	ACTUAL OPERATING (HR)	DOWNTIME (HR)	STANDBY (HR)	REQUIRED OPERATING (HR)	ACTUAL HR REQD HR
WASTE MANAGEMENT					
COMMODE	23.3	0	2,133.2	23.3	1.000
URINE COLLECTOR	2.5	34.9	2,119.1	37.4	0.067
WATER MANAGEMENT					
VD-VF*	1,529	597.5	30	2,126.5	0.720
WICK EVAPORATOR	744	0	1,412.5	744	1.000
HUMIDITY CONTROL	2,156.5	0	0	2,156.5	1.000
POTABLE MULTIFILTER	2,026.8	0	129.7	2,026.8	1.000
WASH WATER RECOVERY	2,156.5	0	0	2,156.5	1.000
ATMOSPHERE PURIFICATION					
SOLID AMINE CONCENTRATOR*	1,662	494.5	0	2,156.5	0.772
MOLECULAR SIEVE	494.5	0	1,662	494.5	1.000
CONCENTRATOR					
TOXIN CONTROL	1,790.5	0	366	1,790.5	1.000
THERMAL CONTROL	2,156.5	0	0	2,156.5	1.000
ATMOSPHERE SUPPLY AND PRES- SURIZATION					
SABATIER REACTOR	1,918.7	104	133.8	2,022.7	0.947
ELECTROLYSIS (ALLIS-CHALMERS)	96	2,036.5	24	2,132.5	0.045
ELECTROLYSIS (LOCKHEED)*	1,492.8	475.3	188.4	1,968.1	0.758
TWO-GAS CONTROL*	2,156.5	0	0	2,156.5	1.000
MASS SPECTROMETER SENSOR*	2,118.8	0	37.7	2,118.8	1.000
BASELINE TWO-GAS CONTROL	0	0	2,156.5	0	1.000
BASELINE TWO-GAS SENSORS	37.7	0	2,118.8	37.7	1.000
*ADVANCED SUBSYSTEM UNIT					

Figure 1.- Summary of LSS operation.

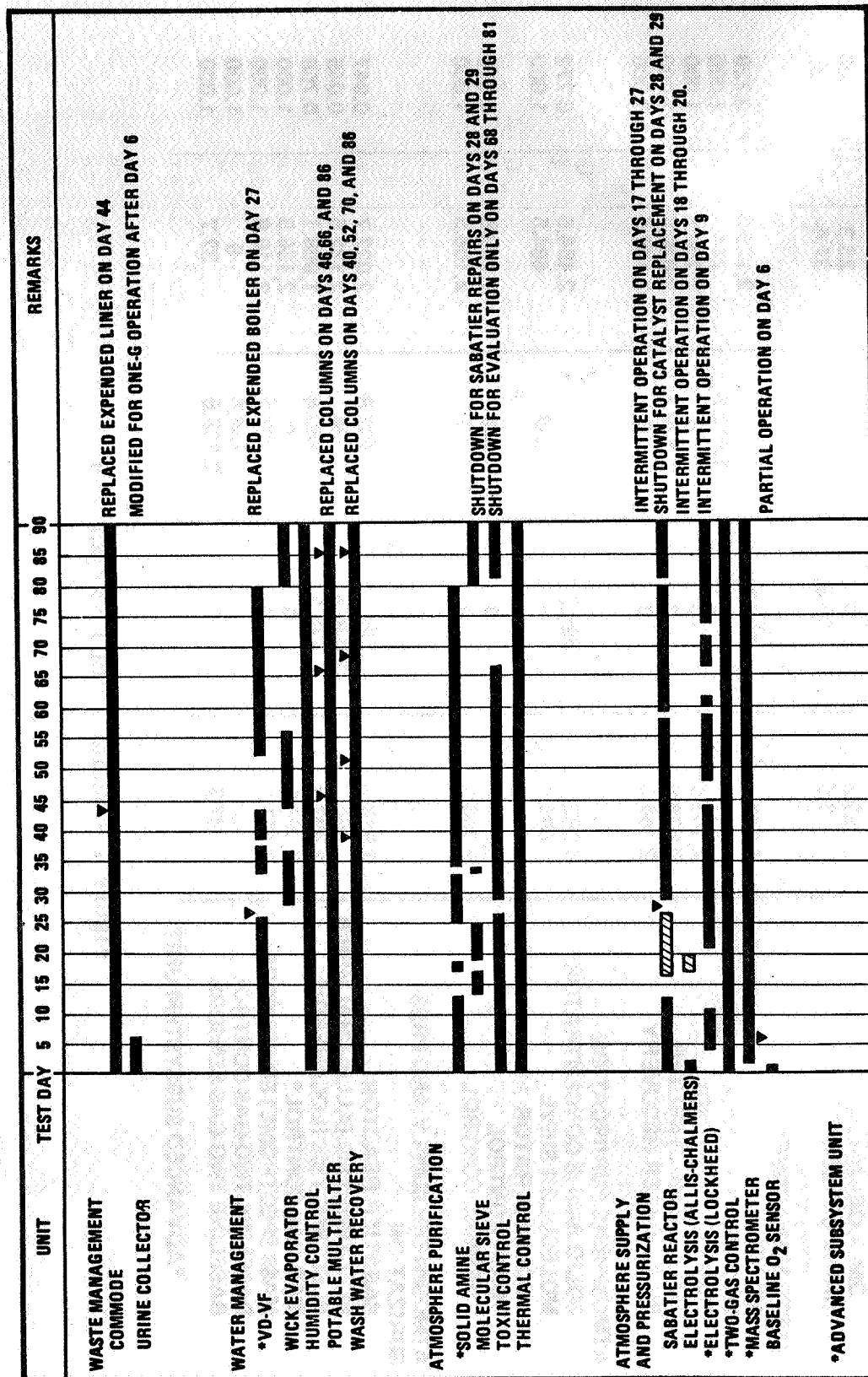


Figure 2.- Life support system operation summary.

LIFE SUPPORT UNIT	REPAIR		MAINTENANCE		UNIT TOTALS	
	ITEMS	HR	ITEMS	HR	ITEMS	HR
WASTE MANAGEMENT COMMODE URINE COLLECTOR	2 8	0.7 14.3	2 0	5.5 0	4 8	6.2 14.3
WATER MANAGEMENT VD-VF*	20 0	19.9 0	1 4	4.0 0.3	21 4	23.9 0.3
WICK EVAPORATOR	3	1.2	30	15.0	33	16.2
HUMIDITY CONTROL	3	5.3	1	0.3	4	5.6
POTABLE MULTIFILTER	18	4.1	1	0.7	19	4.8
WASH WATER RECOVERY						
ATMOSPHERE PURIFICATION SOLID AMINE CONCENTRATOR*	33 7	30.1 3.7	14 1	3.3 0.7	47 8	33.4 4.4
MOLECULAR SIEVE CONCENTRATOR	0	0	0	0	0	0
TOXIN CONTROL	0	0	0	0	0	0
THERMAL CONTROL						
ATMOSPHERE SUPPLY AND PRESSURIZATION	20 47 16	18.6 26.5 83.2	0 0 0	0 0 0	20 47 16	18.6 26.5 83.2
SABATIER REACTOR	0	0	0	0	0	0
ELECTROLYSIS (ALLIS-CHALMERS)	0	0	5	4.1	5	4.1
ELECTROLYSIS (LOCKHEED)*	0	0	0	0	0	0
TWO-GAS CONTROL*	0	0	0	0	0	0
MASS SPECTROMETER*	0	0	0	0	0	0
BASELINE TWO-GAS CONTROL	0	0	0	0	0	0
BASELINE TWO-GAS SENSORS	0	0	1	0.5	1	0.5
LIFE SUPPORT SYSTEM TOTALS	177	207.6	60	34.4	237	242
*ADVANCED SUBSYSTEM UNIT						

Figure 3.- LSS maintenance and repair summary.

ACTIVITY	REPAIR		UNSCHEDULED MAINTENANCE	
	ITEMS	HR	ITEMS	HR
DEFROST REFRIGERATOR	0	0	9	4.5
CLEANED CABIN FLOOR	0	0	9	9.0
CLEANED DEW POINT MIRRORS	0	0	4	1.5
CORRECTED LEAK IN TRASH CONTAINER	2	0.3	0	0
REPAIRED PSYCHOMOTOR PEDAL	1	1.0	0	0
DEACTIVATED SMOKE ALARM HEAD	2	0.7	0	0
REPAIRED RADIATION MONITOR	1	0.3	0	0
REPAIRED PARTICLE COUNTER	1	0.5	0	0
REPLACED VIDECON TUBE	1	0.5	0	0
REPAIRED TV COAXIAL CABLE	5	2.5	0	0
INSTALLED INTERCOM CALL LIGHT	1	1.0	0	0
ATTEMPTED REPAIR OF VISUAL SENSITIVITY TESTER	4	6.7	0	0
TOTALS	18	13.5	22	15.0

Figure 4. - Miscellaneous unscheduled maintenance and repair summary.

EQUIPMENT AFFECTED	SPARE PART USED	NO.
WASTE MANAGEMENT COMMODE URINE COLLECTOR	LINER ASSEMBLY	1
	RELAY	1
	TIMER	1
WATER MANAGEMENT VD-VF	FLOAT SWITCH	1
	RELAY	1
HUMIDITY CONTROL	BOILER ASSEMBLY	1
	PUMP ASSEMBLY	1
	SUMP SCREEN	2
POTABLE MULTIFILTER	PUMP*	1
	CHARCOAL COLUMN	2
	RESIN COLUMN	1
WASH WATER RECOVERY	FILTER	1
	CHARCOAL COLUMN	4
	RESIN COLUMN	2
	FILTER	5

*INSTALLED SPARE

Figure 5. - Major onboard spares usage.

EQUIPMENT AFFECTED	SPARE PART USED	NO.
ATMOSPHERE PURIFICATION SOLID AMINE CONCENTRATOR	FILTER	11
	COMPRESSOR*	1
	BLOWER*	1
	WATER PUMP*	1
	SOLENOID VALVE	1
	CHECK VALVE	1
MOLECULAR SIEVE CONCENTRATOR		
ATMOSPHERE SUPPLY AND PRES- SURIZATION		
SABATIER REACTOR	CATALYST REFILL	1
	CONDENSER	1
ELECTROLYSIS (ALLIS- CHALMERS)	ELECTROLYSIS MODULE	2
	ZENER DIODE	2
	PRESSURE REGULATOR	2
BASELINE TWO-GAS SENSORS	POLAROGRAPHIC SENSOR	1
MISCELLANEOUS		
COMMUNICATIONS	VIDEOCON TUBE	1
RADIATION MONITOR	PHOTOMULTIPLIER TUBE	1
* INSTALLED SPARES	TOTAL SPARES	52

Figure 5. - Concluded.

DEVELOPMENT OF CREW SELECTION GUIDELINES FOR THE 90-DAY MANNED TEST

By Rayford T. Saucer
NASA Langley Research Center

SUMMARY

A panel or steering committee of behavioral scientists was created to advise NASA AND MDAC operations personnel on selection methods for the crew. The panel, acting in an advisory capacity, made recommendations concerning crew selection, monitoring, and assessment. A generalized concept of crew selection for long duration missions was developed on the basis of motivation, skill levels, emotional maturity, and observations of group compatibility.

INTRODUCTION

The plan for the 90-day manned test was to minimize the passing in or out of materials, to avoid opening the test chamber except in case of emergency or total systems failure, and to make maximal use of the onboard crew for operation, maintenance, and repair of the life support systems. These and other constraints indicated that the crew would undergo a high degree of physical confinement in a relatively small space for the duration of the test.

The triad of confinement, isolation, and monotony is potentially stressful for many people. While it was expected that the confinement aspect of the test would be real, preliminary study indicated that the communications flow would be high and that the activity within the chamber would be diversified. With a four-man crew and a high communications flow, isolation per se seemed to pose no real problem. The varied activity within the chamber suggested that the mission would not become monotonous. The absence of these two factors (isolation and monotony) tended to focus concern on the motivation of the individual crewmen and the psychosocial integrity of the crew. Low motivation and interpersonal stresses arising from relative confinement, low habitability, and incompatibility could conceivably precipitate a crew-initiated abort. Such an action would result in a consequent loss of a large amount of engineering data.

In many ways the successful 1969 Tektite 1 study (ref. 1) seemed to offer a conceptual model for the 90-day manned test. In this study four marine scientists remained below the ocean for 60 days while executing a variety of research projects. Except for the degree of freedom allowed by relatively short periods of exploratory diving, the habitat and task loading for the Tektite 1 study were similar to those projected for the 90-day test. The crew members were primarily responsible for the planning of the oceanographic research and for gaining acceptance of the program within the Department of Interior, where they were employed. They had formed an ad hoc group of like-minded individuals who were convinced that serious marine research could be carried on by using saturation diving techniques. In addition, each member of the group had a

strong personal interest in a particular area of oceanography and was motivated by the prospect of publishing important technical and scientific papers in his area of interest.

Overall results of this effort suggested that a small group can form a viable micro society and withstand both individual and interpersonal stresses if individual motivation is high, if the group is compatible, and if there is a supraordinate goal to hold the group together. It seemed feasible, therefore, to apply some of these emerging concepts to the problem of manning the 90-day test.

These concepts, together with work by Sells in establishing models of micro societies (ref. 2) and unpublished work on interpersonal compatibility by W. W. Haythorne and Seward Smith of the Naval Medical Research Laboratory, offered the possibility of formulating a crew selection procedure with definite goals. The goals of the selection procedure were to minimize the possibility of a crew-initiated abort, to minimize the effects of stress on the individual crewmen, and to offer a realistic reward for successful completion of the mission.

APPROACH

The behavioral program for the 90-day test was seen not as a trial of human endurance but rather as an attempt to aid the success of the mission by supplying knowledge of small-group processes and dynamics.

A panel of experts in small-group dynamics was assembled. Operations personnel from the National Aeronautics and Space Administration and from McDonnell Douglas Astronautics Company were included in the meetings so that direct contact with the project could be established and maintained.

An exploratory meeting was held at NASA Langley Research Center and a definitive meeting was later held at Texas Christian University. During the first meeting it was decided that the panel could best serve in an advisory capacity to the NASA and MDAC. The panel felt that it would be able to help provide a rationale for crew selection, monitoring, and final assessment of crew status. The second meeting addressed itself to both the problem at hand and the extended problem of small crews for long duration missions in general. The report of this second panel meeting has not yet been formally published; this delay is due, in part, to the fact that informal communication between the panel, NASA, and MDAC was ongoing until the final selection. Since the second meeting was held some time before the final selection, it may be that some ideas which were emergent during the meeting became more definitive at later stages. The present paper reflects most of the spirit and substance of the panel meetings with perhaps some slight changes in emphasis and with some reorganization.

DISCUSSION

The suggested method of implementing the goals of the selection procedure can be outlined.

The most important factor in selection was believed to be motivation. In the present context motivation was defined as career motivation; that is, the mission participation would be seen by the individual as an opportunity which would significantly affect his future career. Thus, it was suggested that university graduate students majoring in technical areas relevant to the 90-day test would provide an appropriate subject pool. This recommendation was adopted, and a prospectus was circulated to major universities within the Los Angeles area. Over 30 responses followed. It is likely that more could have been secured had the prospectus been circulated nationwide.

Pursuant to the present definition, motivation could be assessed by active career interest and a relevant educational program, by academic standing, by faculty recommendation, and by interviews.

During the course of continuing interaction between the panel and the operations personnel, it became evident that much of the success or failure of the mission would depend upon engineering, mechanical, and technical skills and aptitudes of the crew. A task analysis was suggested, to be followed by definition of jobs or task areas. Selection procedures could then be defined in terms of relevant study areas, work history, and interest patterns. Further evaluation could be carried out during the systems training period before the final crew was chosen.

The next definitive step involved a medical examination and assessment of psychological health and emotional maturity. None of the selected crewmen had a history of a major physical disease and none had evidence of psychiatric difficulty. After some members of the original pool had withdrawn because of academic schedules or other pressures, the remainder were administered a comprehensive psychodiagnostic battery by a licensed clinical psychologist. The scores were then forwarded to the panel for study and concurrence.

Given active motivation, relevant work history, and personal stability and emotional maturity, group compatibility became the desired objective. This objective in fact was combined in part with the final step, selection of the crew by operations personnel. It was felt that the decision of the operations personnel would provide a backup to the other procedures and would probably provide the best assessment of work skills. In addition, since the onboard crewmen would be continuously working with each other and with the outside crew, an opportunity for observation of group compatibility would exist.

The panel also recognized the fact that the onboard crew would be integrated into a complex organizational and technical structure. It therefore recommended several constraints in this area. For example, it was believed that some necessary degree of structure might be obtained by designating a crew chief. It was suggested that he be selected before the beginning of the test but as late as possible so that his leadership potential and acceptance could be evaluated.

It was recommended that if at all possible, he be the older, more experienced member of the crew with some experience in total systems concepts so that status congruence could be preserved.

In order to achieve a useful simulation, it was recommended that the simulation be characterized as an experimental test of a prototype space system and that the major task of the crew be defined as the operation, maintenance, and repair of the system. All irrelevant tasks were to be eliminated if possible and only tasks relevant to a real life work situation were to be retained. If possible, the onboard crewmen were to be integrated with operations personnel in such a way that they would share a common goal of completing a significant engineering experiment. It was also suggested that some opportunity be provided for the crew to design and carry out bona fide research projects during the mission.

Finally, it was suggested that all relevant aspects of the mission such as the necessity for behavioral studies, tasks, and observations be frankly and openly discussed with the crew so as to avoid misunderstandings and surprises during the course of the test.

In post-test discussions with both NASA and MDAC project managers, the panel ascertained that the crew met the managers' expectations with regard to psychosocial integrity and with regard to performance. They responded well to both emergencies and prolonged repair and maintenance tasks. Such minor onboard problems in interpersonal relationships as occurred were probably negligible in their effect on the total systems operation. At no time was there any pronounced schism between the onboard and outside crews.

This compatibility may have been in part due to the emotional maturity of the onboard crew and in part due to some evident feeling that the onboard crew was an elite, intelligent, and knowledgeable group of individuals.

CONCLUDING REMARKS

It is quite possible that the recommendations of the panel were too general, but the intent was to provide a generalized schema of crew selection without defining the actual selection program in detail. In review, the schema provided cannot be said to be novel. It consisted of plans to choose highly motivated individuals who had the requisite work skills, emotional maturity, and group compatibility to withstand the mission stresses and to execute the task of operating the onboard systems. These qualifications were assured in part by formal testing and examination and in part by critical on-the-job selection. In retrospect, this schema should apply in general to personnel selection for hazardous or demanding missions.

If the schema was successful for the selection of the crew for the 90-day test, a large part of the success was due to the close cooperation between the behavioral science community and the responsible NASA and MDAC project managers.

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CREW SELECTION

By J. S. Seeman and M. V. McLean

McDonnell Douglas Astronautics Company

SUMMARY

The successful selection of crewmen for the 90-day manned test was a major contribution to the total study. A highly selected group of individuals was screened and evaluated for compliance with numerous criteria relating to their acceptability and ability to withstand isolation stresses.

Results of the crew selection process indicate that crew selection was an important contributor to the overall success of the 90-day test. In addition, quantitative psychological criteria have been developed which can be employed on future studies of this nature.

Certain limitations in the use of psychological testing techniques have been identified and the importance of pragmatic aspects of personnel selection has been demonstrated.

INTRODUCTION

Crew selection for the 90-day test was the most comprehensive selection program ever applied to a simulation study. The selection program had the objective of choosing a crew that would function effectively and efficiently for the total test duration and do so with no subsequent pathology. Selection techniques were psychologically oriented, but also placed a great deal of emphasis on the more pragmatic aspects of crew suitability such as mechanical skills; availability for training; physical fitness; health of close family members; motivation for participation; and acceptance of pay scales offered.

PROCEDURES

Three lines of selection were followed: psychological, physical, and pragmatic. Criteria were developed within each area. Throughout the multi-stage selection process, consonance of volunteers with these criteria was sought. An overview of the selection process is presented in table 1.

Psychological Criteria

At the request of the contractor, a NASA-sponsored symposium was held at the Institute of Behavioral Research, Texas Christian University, to develop criteria and procedures for crew selection. Symposium panel membership consisted of the following personnel:

E. K. Eric Gunderson, Ph. D.

Director, Special Environments Division
US Navy Medical Neuropsychiatric Research Unit
San Diego, California

William Haythorn, Ph. D., Director
Behavioral Sciences Department
Naval Medical Research Institute
National Naval Medical Center
Bethesda, Maryland

R. Mark Patton, Ph. D.
Chief, Human Performance Branch
NASA Ames Research Center
Moffett Field, California

James R. Rawls, Ph. D. (Now at Vanderbilt University, Nashville, Tennessee.)
Associate Research Scientist
Institute of Behavioral Research
Texas Christian University
Fort Worth, Texas

Rayford T. Saucer, Ph. D. (Co-chairman)
Consultant
Stop 310, NASA Langley Research Center
Langley Station, Hampton, Virginia

Mr. Jerome S. Seeman
Behavioral Director - 90-Day Manned Test
Advance Biotechnology and Power Department
McDonnell Douglas Astronautics Company
Huntington Beach, California

Walter L. Wilkins, Ph. D.
Scientific Director
US Navy Medical Neuropsychiatric Research Unit
San Diego, California

S. B. Sells, Ph. D. (Co-chairman)
Director, Institute of Behavioral Research
Texas Christian University
Fort Worth, Texas

The resulting recommended process was a multistage screening necessitating demonstration among crew candidates of:

- A. Scientific and technical skills and capabilities.
- B. Emotional maturity and mission motivation.
- C. Physical health.
- D. Ability to withstand isolation.
- E. Leadership identification.
- F. Crew compatibility.

Information concerning quantitative scores of the various psychological tests for each of these areas was not available. Consequently no quantitative criteria existed for crew selection based upon psychological tests and what was recommended consisted of a technique of multiscreening based upon judgment of the screeners.

A consultant in clinical psychology (Dr. T. MacFarlane) administered tests, scored them, and recommended candidates from among those applicants sent to him for psychodiagnosis. Dr. MacFarlane generated, by MDAC request, a quantitative profile of scores on the various objective psychodiagnostic tests, which were on an a priori basis thought to describe the kind of person expected to be most effective in withstanding the rigors of confinement.

Physical Criteria

Physical criteria consisted of the ability to pass an FAA Class I physical examination and demonstrated compliance with normal values of a number of biochemical indices.

Pragmatic Criteria

Pragmatic criteria included:

- A. Willingness to volunteer for the entire program.
- B. A demonstrated life style indicative of inner-directedness with little dependence on other persons for emotional stability.
- C. No criminal arrests or convictions.
- D. No serious speech impediments.
- E. No evidence that participation in the program reflected an escape from life.
- F. No previous history of serious emotional difficulties.
- G. Commitment to the achievement of higher academic goals in graduate school.
- H. Interest in becoming an astronaut.
- I. Previous history of small group confinement or isolation experiences.
- J. Experience with construction, repair, and/or maintenance of electro-mechanical devices.
- K. Older than 21 years.
- L. Height and weight consistent with volumetric provisions of SSS.
- M. Minimal history of psychosomatic illness.
- N. No serious physical illnesses among close relatives or friends.

Applications were solicited from graduate schools in the Southern California area within the disciplines of engineering, physics, biology, and the social sciences. Contact was established between representatives of MDAC and the personnel offices at the various universities. These contacts permitted an explanation of the 90-day test to be relayed to officials of the schools and also afforded the opportunity to request that applications for membership in the candidate pool be limited to those graduate students whose major professors would recommend and concur in the application. Approximately 45 applications were received.

The 27 who survived the initial screening and appraisal interviews were identified on the basis of initial screening and approval interviews by the Behavioral Director, as well as through review of screening questionnaires obtained before the interviews. Reasons for exclusions from this group included monetary incentives being primary as a motivational force in volunteering, imminent school failure, ill health of close family members, history of serious emotional difficulties, etc.

Psycho-diagnostic tests (objective and projective) were next given to 16 individuals identified as most desirable of the 27. Test profiles were developed by MDAC and its consultant at this point, which were thought to be descriptive of the "classical" crewman. Accordingly quantitative values were established consisting of ranges wherein each applicant's scores should fall. Objective tests given were:

- A. MMPI (Minnesota Multiphasic Personality Inventory)
- B. FIRO-B
- C. 16 PF (Forms A and B) (16 Personality Factors)
- D. MAT (Motivational Analysis Test)
- E. Study of Values - Allport/Vernon
- F. Edwards PPS (Personal Preference Schedule)
- G. Rokeach Dogmatism Scale
- H. Eysenck Personality Inventory

Projective tests used were:

- A. Rorschach
- B. Thematic Apperception Test
- C. Sentence Completion
- D. Early Parental Recollections
- E. Future Autobiography

The formal crew pool (eight) was chosen on 26 January 1970. Training began the following week. Throughout the training period the men were observed for group formation and the evolution of a leader. Immediately prior to the 5-day run, a sociometric test was given as an adjunct to aid in crew selection. This combined with training results and, to an extent, individual availability led to the selection of a four-man crew. Crew performance was outstanding during the trial run and gave a great deal of confidence in the selection process.

Subsequent to the 5-day run, a review and evaluation was accomplished that gave valuable information for hardware and procedural modifications.

Final crew selection occurred on 26 May 1970 and was achieved through the consensus of the Program Manager, Medical Director, and Behavioral Director following an evaluation of all the pertinent data, i. e., training results, psychological data, subsystem knowledge, health data, etc.

RESULTS

Table 2 presents an overview of the major findings of the selection effort. The success of the selection program is attested to by the fact that all four men selected withstood 90 days of confinement with no serious hostilities developing and no indication of any intent to abort the mission. All scheduled tasks were performed throughout the 90-day period promptly and conscientiously.

Following the 90-day test, initial review of objective psychological test results indicates that there is no apparent consequent pathology. Projective tests are scheduled for the immediate future, but no surprises are expected.

Selection criteria for the objective psycho-diagnostic tests have been developed which are quantifiable and apparently valid. This is considered to be a major contribution to future quantitative crew selection procedures. The objective of scientific and technical capabilities was obviously met as the crew learned the subsystems and they operated well with outside crew support.

A feature of selection not originally planned, but of considerable value in the ultimate selection, was the demonstrated ability of selected candidates to comply with the many irritating, time-consuming, and constantly changing infringements on their time throughout the training program. Crewmen were thus additionally selected on the basis of accepting these requirements without complaint.

Another feature originally intended to be used (observation of group structure throughout training) proved to be of less value than originally expected because a cohesive group was not firmly developed. Attention to the personality characteristic of inner-directedness during the selection process apparently worked toward mitigating the development of a strongly cohesive group. These individuals were too inner-directed to permit the penetrations necessary for the establishment of such a group.

CONCLUSIONS

Crew selection is not a highly exact process of matching test results with pre-existing criteria. Throughout selection, human judgments and hypotheses as to acceptability must be continuously advanced, discussed and reevaluated. Because no test or group of tests yet exists which can be totally relied upon, iterative consensual human judgment and intuition serve as the primary selection mechanism. Thus, selection of the selectors looms as of paramount importance in the accomplishment of successful crew selection of members of long-duration space missions.

A great deal of time was necessary to the selection of the crew. It is felt that too much emphasis was placed upon psychologically based crew selection techniques which is inconsistent with the degree of confidence currently existing in the adequacy of these techniques.

The points already made emphasize the tenuous nature of existing psychologically based crew selection techniques. It would be highly desirable to explore the possibility of increasing the validity of selection methods. Rather than reexamining and validating psychological selection tests, it seems more reasonable to investigate alternate selection techniques deriving from other disciplines.

TABLE 1.- CREW SELECTION

OBJECTIVES

HOMOGENEITY OF PERSONALITY CHARACTERISTICS

HIGH MOTIVATION

PRECLUSION OF CONSEQUENT PATHOLOGY

ABILITY TO LEARN SUBSYSTEM OPERATIONAL REQUIREMENTS

ELIMINATION OF INTER-CREW HOSTILITIES

EMOTIONAL STABILITY

PROCEDURES

- FORT WORTH SYMPOSIUM -- RECOMMENDED PROCEDURES (21, 22, 23 MAY 1969)
- LIMITED APPLICATIONS -- GRADUATE SCHOOLS AND DISCIPLINES (OCT 1969)
- APPRAISAL INTERVIEW -- AVAILABILITY, INTEREST, HISTORY, AND OBVIOUS PHYSICAL INCOMPATIBILITIES (NOV 1970)
- SCREENING TESTS -- MDAC, NMRI, AND NMNRU (DEC 1969)
- PHYSICAL EXAMS (JAN 1970)
- PSYCHODIAGNOSTICS -- DEVELOPED QUANTITATIVE CRITERIA (JAN 1970)
- IDENTIFICATION OF CREW POOL (26 JAN 1970)
- TRAINING, INCLUDING COHESION TRAINING (STARTED 2 FEB 1970)
- EVALUATION OF TRAINING AND CREW FORMATION -- TESTS AND OBSERVATIONS (JAN TO APR 1970)
- SELECTION FOR 5-DAY MISSION (APR 1970)
- REVIEW AND EVALUATION OF 5-DAY CREW PERFORMANCE (8 TO 15 MAY 1970)
- SELECTION FOR 90-DAY MISSION (26 MAY 1970)

Table 2
RESULTS OF CREW SELECTION PROCESS

Achieved fair homogeneity of personality characteristics

High motivation

No apparent consequent pathology

Identification of apparently valid and numerically
describable selection criteria

Excellent learners—Subsystems operated with crew support

Minimal manifestations of crew hostilities

CREW TRAINING

By R. E. Shook and J. S. Seeman

McDonnell Douglas Astronautics Company

SUMMARY

The purpose of the crew training program was to prepare candidates for effective participation in the 90-day manned test. Curriculum coverage was accomplished over an approximate 6-month period and consisted of training in experiment operations, safety procedures, equipment operating procedures, and maintenance and data collection requirements.

The training program contributed significantly to the success of the 90-day manned test insofar as it provided a well-trained, highly motivated crew for integration with the operations required onboard the Space Station Simulator (SSS).

INTRODUCTION

The goals for training at the beginning of the program emphasized the need for crew competence and safety. The basic requirements included candidates with good basic scientific training and aptitudes, experienced instructors, a thorough curriculum, and a flexible schedule. The preliminary organization of instructor staff and curriculum development is dependent on staff experience and abilities and can be formed in a relatively straightforward manner. After development, the training program becomes dependent on the availability of the staff, crewmen, and training equipment, all of whom have other demands on their time and attention. The development and use of an accommodating schedule permits maximum interaction of the crew and instructors.

PURPOSE

Crew training served the dual functions of providing information to the crew on test objectives and operational requirements, as well as providing information on the crew regarding levels of motivation for use by program management as pragmatic inputs to crew selection.

ORGANIZATION OF TRAINING

The organization of training began with the appointment of a training staff consisting of a training director and instructors for each course. The Program Manager, with the Behavioral Director, appointed the staff of instructors and the training director. The training director reported to the Behavioral Director and was responsible for curriculum development, scheduling, and all crew/staff interactions. The training curriculum was developed by each instructor submitting a course outline that specified subject matter to be covered and performance requirements for the crew candidates. The preliminary schedule was developed by the staff from these outlines and the scheduled development of the test equipment.

CURRICULUM

The basic curriculum consisted of lectures, demonstrations, and practice sessions. Lectures were used to familiarize the crew with equipment operation and maintenance, medical and behavioral methodology, test procedures, and requirements. There were three basic areas in the curriculum: (1) biomedical, (2) life support systems, and (3) man/systems integration and operation.

The distribution of course work under these headings can be seen in table 1 and Appendix A.

The crewman performance evaluation for this curriculum consisted of a crew proficiency rating (table 2) filled out by each instructor after the completion of his class and evaluation period, a crew course rating filled out by the crewman candidates (table 3), a self-evaluation by each candidate of his own knowledge of the systems, and three written tests administered periodically during the course of training.

The first of the three written tests was relatively unstructured and requested that the crewmen describe what they knew of the systems they had studied and what they understood of the objectives of the 90-day test. The intent in giving this type of test was to assess the effectiveness of the training to date, to find those areas the crewmen were interested in and responded best toward, and to see how each crewman structured his concepts of the whole program; i. e., whether he responded with detailed analyses of the equipment and processes or was concerned with the larger view. The crewmen's scores on this test were not used for comparative evaluations because they responded in different ways. Some went into little detail system by system, but gave a good comprehensive view of the program. Others provided considerable detailed description of the processes and hardware of the life support equipment. These differences had a beneficial effect because in this competitive situation it demonstrated the various viewpoints and grasp of detail possessed by other candidates and clearly defined the nature of the selection competition. The second written test concerned the life support systems and asked for details of hardware and processes. The last test was, in effect, a final

examination consisting of questions submitted by instructors from areas requiring detailed system descriptions and procedural methodologies. This last test and the instructors' evaluations were given the most weight in evaluation of the candidates.

The candidates were graduate students from several local universities and adapted very readily to the laboratory and the type of training. (Their graduate studies were more arduous than the simulator training.) All of the candidates had had previous training that was directly applicable to some area in the program. One candidate was experienced in veni-puncture techniques and blood handling, several had taken bacteriology classes, and all had taken sufficient chemistry courses so that they readily understood the life support processes. All had had experience in operating test equipment and computer techniques. Their advanced degree goals in engineering and the sciences also demonstrated the very important attribute of being concerned with this type of program, the experiments, and knowing the value and need of good data.

Cross-training of the crewmen was quite extensive in the first part of training. All members of the final group practiced veni-puncture techniques, urinalysis, and sterile techniques for microbiology. All attended the lectures on life support equipment and practiced the man/system procedures and psychomotor devices.

Cohesion training was a form of sensitivity training oriented to the development of a cohesive group consisting of crewmen and communications monitors. It was undertaken in an attempt to eliminate intercrew difficulties. Cohesion training consisted of six sessions of varying length. The first session was 6 hours long with seven crewmen and four communications monitors participating. The group director was an MDAC consultant, Dr. MacFarlane. The last session consisted of eight crewmen, two communications monitors, and Dr. MacFarlane.

As training progressed and particularly after final crew selection, the amount of cross-training was lessened, and with some experiments none was done. The particle counting experiment procedure, light measurement, and mass balance data management were assigned to particular crewmen. The microbial monitoring technique was taught to two crewmen. Two crewmen were selected for EEG monitoring and taught the required procedures (paper no. 38 of this symposium).

The following chart shows the training hour distribution. All values are in man-hours.

<u>Lecture and Demonstration</u>	<u>Practice</u>	<u>Miscellaneous (EEG Sleep)</u>	<u>Written Test</u>	<u>Total Training</u>
853	893	44	80	1, 870

There was some difference between crewmen in the number of hours each attended training. After crew selection, there was more demand to train those selected in particular fashions relating to their anticipated onboard roles.

The scheduling of training was the most persistent problem throughout the pretest period. In the beginning of the training period, the class schedules of the crewmen became the controlling factor for their training schedule. The class schedule factor gradually diminished because those crewmen with large class and workloads withdrew from school as they became more involved in the 90-day test classes. Another type of scheduling problem appeared and remained throughout the training period. This was the coordination of crew time with the instructors involved in the process of developing, testing, and installing a piece of life support equipment. Occasionally, an early lecture and demonstration would have to be redone when the equipment was modified after additional testing and instrumentation and other devices added.

Biomedical and man/systems experienced relatively little difficulty in scheduling of training. The demand for practice time by some of the equipment, such as the ergometer and human describing function device, could not be met on all days because of limited opportunities for demonstrations and practice on other equipment. As blood analysis was begun, the crew arrived in a fasting condition every Tuesday morning and practiced blood and urine sampling, microbiological techniques, food management, and waste material handling. The requirement to arrive fasting every Tuesday morning depended upon the crewmen and was met with few exceptions. This type of coordination was more the exception than the rule.

Occasionally, the availability of a particular instructor or equipment required rescheduling of a class and the reduction in the number of crewmen given certain kinds of training. This was true of the electrolysis units and the solid amine CO₂ concentrator because other companies developed these units and assisted in the crew training. Some computer training was given after regular work hours to have more nearly uninterrupted access to the computer.

Maintenance training was variable for each item. On some items, installation and instrumentation occurred late in the prerun period and the available training time was used to teach operation. Major overhaul type maintenance was not taught as it was felt that most equipment would operate with only minor electrical and mechanical malfunctions. Some units had a considerable history of operation without failure before the 90-day test. In-depth maintenance training was not practical for most of the life support equipment because of the complexity of their respective control systems. The schedule seldom permitted adequate time to practice maintenance on equipment undergoing final test, instrumentation, and installation.

In the biomedical lectures and demonstrations, there were few or no difficulties and the practice requirements allowed adequate scheduling flexibility. Similarly, the man/systems lectures and demonstrations introduced few difficulties and permitted flexibility in scheduling. The final sessions of cohesion training had to be postponed once or twice. This apparently had little impact on the class. Practice on the psychomotor devices was interrupted while they were being installed in the simulator, but this was a relatively small amount of time compared to the whole practice time.

The life support systems presented the most difficulty in scheduling. Lectures and demonstrations depended on the performance and acceptance of the equipment. It was intended to operate and practice maintenance on installed units. This was possible on some of the units, the thermal control for example, but on others, because of time constraints, lectures and demonstrations were accomplished outside the simulator. Some units were started up outside the simulator and then again after installation, with maintenance practiced after the pretest 5-day run.

The instructors for the three areas of training were drawn from the respective branches of the MDAC Biotechnology Department and from other contributing companies and Government agencies. The instructors for the biomedical and man/systems areas were specialists in those disciplines applicable to specific classes. For example, a specialist with radiological training and experience was assigned to isotope handling. The instructors for the life support equipment were the principal investigators for each piece of equipment. The instructors outside MDAC were generally the principal investigators or their assistants for those experiments and pieces of equipment.

The previous test experience of the instructors was invaluable because it provided a base of knowledge of what would be required. They devoted considerable extra time to course preparation and outside working hours instruction, demonstration, and testing of the crewmen. Generally, they appeared to take personal interest in the preparation of the crew.

The instructors were evaluated by the crewmen on the crew course rating (table 3) form (and by occasional remarks). These results can be employed to improve the content and delivery of future comparable training programs.

A tabulation of MDAC capabilities brought to bear upon training for the 90-day test is shown in table 4.

CONCLUSIONS

The training program was a contributing factor to the successful accomplishment of the 90-day test. The performance of the crew throughout the run showed little of those characteristics of ineffectual training, such as operating indecision, poor or hasty procedural judgments, missed data, and overdependence on outside direction; especially as the mission progressed. Without competent crewmen, interested in and responsive to the needs of principal investigators and engineers, the 90-day test could not have been successful.

For long-duration simulations of this type, a training program must be flexible with respect to schedule and changes in subject matter. The subgoals of these studies evolve throughout the preparation period. The equipment design and installation schedules must be altered and access periods to these units changed. All these contribute to changing the training curriculum in content and in schedule.

In the case of graduate students, the program schedule should accommodate the school schedule as far as is possible. Matching of subjects' aptitudes to the program reduces training problems on both ends of the spectrum.

In addition to adequate subjects and a flexible program, experienced instructors further ensure an adequate training program. They know what is required, how to transmit this information to the subjects, and how to evaluate performance.

In future training programs it may be desirable to compress and concentrate training over a shorter period after subsystems have been received, installed, and integrated. This could significantly improve the adequacy of remedial maintenance instruction which during the 90-day test consisted essentially of on-the-job training during early stages of the test.

Cohesion training seems to have been effective in reducing the frequency and the severity of intercrew difficulties. Post-test interview material suggests that crewmen would have preferred to have had greater exposure to the cohesion training portion of the overall training program. This finding is consistent with results obtained on the 60-day test concluded in 1968.

Appendix A

SSS CREW TRAINING CURRICULUM

INDEX

Biomedical Procedures

- Microbiology
- Medical Monitoring
- Blood Sampling
- Urine Sampling
- Physical Fitness
- Experiments

Life Support Systems

- Water Subsystems
- Atmosphere Control
- Mass Balance

Man/Systems Integration and Operation

- Human Factors
- SSS Procedures
- Support Functions
- Experiments

COURSE AREA: Biomedical Procedures

COURSE TITLE: Microbiology

COURSE OBJECTIVE: To train crewmen to perform bacterial sampling and counting, and operate the experimental equipment

COURSE OUTLINE:

1. Classroom
 - A. Introduction
 - B. Sampling and Counting
 - C. Sterile Techniques
 - D. Potable Water Protocol
 - E. Experiments
2. Practice

Each crewman will perform the sampling and counting operations using sterile techniques under the direction of the instructor. Several crewmen will be selected to specialize in experiment performance and bacteriological protocols

CRITERIA FOR CERTIFICATION: Satisfactory demonstration of manual techniques and knowledge of microbiological methodology.

COURSE AREA: Biomedical Procedures

COURSE TITLE: Medical Monitoring

COURSE OBJECTIVE: To train crewmen in the correct application and use of monitoring equipment

COURSE OUTLINE:

1. Classroom
 - A. Introduction
 - B. EKG Electrode Application
 - C. Respiration Rate
 - D. Body Weight
 - E. Blood Pressure
 - F. Oral Temperature
2. Practice

Each crewman will practice each function under the supervision of the instructor. Several crewmen will be selected to specialize in these measurements

CRITERIA FOR CERTIFICATION: Satisfactory performance for each medical measurement

COURSE AREA: Biomedical Procedures

COURSE TITLE: Blood Sampling

COURSE OBJECTIVE: To train crewmen in safe and accurate sampling techniques and assessment

COURSE OUTLINE: 1. Classroom

- A. Sampling Introduction
- B. Veni-Puncture Technique
- C. Blood Smear Procedure
- D. Hematocrit
- E. Vacutainer Preparation
- F. Hemoglobin Determination
- G. Waste Material Handling

2. Practice

Each crewman will practice each function under the supervision of the instructor. Several crewmen will specialize in the sampling and analytical procedures

CRITERIA FOR CERTIFICATION: Satisfactory performance for each procedure

COURSE AREA: Biomedical Procedures

COURSE TITLE: Urine Sampling

COURSE OBJECTIVE: To train crewmen to perform accurate analysis

COURSE OUTLINE: 1. Classroom

- A. Voiding and Measurement
- B. Specific Gravity Determination
- C. Labstix Analysis
- D. Sample Preparation
- E. Waste Material Handling

2. Practice

Each crewman will perform each function under supervision.

CRITERIA FOR CERTIFICATION: Satisfactory analysis, preparation, and sampling techniques demonstrated for the instructor

COURSE AREA: Biomedical Procedures

COURSE TITLE: Physical Fitness

COURSE OBJECTIVE: To condition the crewmen to an acceptable level of physical condition

COURSE OUTLINE:

1. Classroom
 - A. Introduction
 - B. Ergometer
 - C. Treadmill
 - D. MRM (paper no. 39 of this symposium)
2. Practice

Each crewman will exercise as directed by the instructor to achieve and maintain the specified level of physical conditioning

CRITERIA FOR CERTIFICATION: Achievement of prerun fitness baseline

COURSE AREA: Biomedical Procedures

COURSE TITLE: Biomedical Experiments

COURSE OBJECTIVE: To train crewmen in the use and operation of the experimental test equipment

COURSE OUTLINE: 1. Classroom

A. Silver Ion Generator (not used)

B. Visual Tester

C. Glycerol-Based Drink

D. Spirometer

2. Practice

Each crewman will operate the equipment under the instructor's supervision.

CRITERIA FOR
CERTIFICATION: Acceptable performance on all items

COURSE AREA: Life Support Systems

COURSE TITLE: Water Subsystems

COURSE OBJECTIVE: To train the crew to operate and maintain the water subsystems so as to ensure their safety and collect meaningful data.

COURSE OUTLINE:

1. Classroom
 - A. Air Evaporator Unit
 - B. Wash Water Unit
 - C. VD-VF Unit
 - D. Isotope Handling
 - E. Potable Tank Procedures
 - F. Multifiltration Unit
 - G. Water Dispenser
 - H. System Changeover
 - I. Sampling Protocol
 - J. Contamination Procedure
 - K. Backup Water
 - L. Waste Management
2. Practice

Each crewman will practice startup, operation, and shutdown of all equipment. Several crewmen will be selected to specialize in life support systems operation and maintenance.

CRITERIA FOR CERTIFICATION: Satisfactory demonstration of equipment operations and maintenance

COURSE AREA: Life Support Systems

COURSE TITLE: Atmosphere Control

COURSE OBJECTIVE: To train the crew to operate and maintain the atmosphere control systems in a safe and efficient manner.

COURSE OUTLINE:

1. Classroom
 - A. Two-Gas Control Unit
 - B. Thermal Control
 - C. CO₂ Concentrator
 - D. Sabatier Reactor
 - E. Toxin Burner
 - F. Electrolysis Unit
 - G. Atmosphere Particle Counter

2. Practice

Each crewman will practice startup, operation, and shutdown of all equipment. Several crewmen will be selected to specialize in life support systems functions.

CRITERIA FOR
CERTIFICATION: Satisfactory demonstration of equipment operation and maintenance.

COURSE AREA: Life Support Systems

COURSE TITLE: Mass Balance

COURSE OBJECTIVE: To instruct the crewmen in the collection of meaningful data, the critical parameters, and expected values for all the data.

COURSE OUTLINE:

1. Classroom
 - A. Engineering Monitoring
 - B. Water Balance Analysis
 - C. Data Management
 - D. Crew Life Support Monitor
2. Practice

CRITERIA FOR CERTIFICATION: Class attendance and demonstrations of knowledge of mass balance fundamentals and data collection

COURSE AREA: Man/Systems Integration and Operation

COURSE TITLE: Human Factors

COURSE OBJECTIVE: To train crewmen in techniques and goals of the behavioral program

COURSE OUTLINE:

1. Classroom
 - A. Cohesion Training
 - B. Questionnaires and Tests
 - C. Data Collection
2. Practice

CRITERIA FOR CERTIFICATION: Attendance and participation in classroom

COURSE AREA: Man/Systems Integration and Operation

COURSE TITLE: SSS Procedures

COURSE OBJECTIVE: To train crewmen in operation of simulator and living functions in a safe and efficient manner

COURSE OUTLINE:

1. Classroom
 - A. SSS Familiarization
 - B. Pass-Through-Port Operation
 - C. Lock Operation
 - D. Contingency Procedures
 - E. Food Management
 - F. Oven Operation
 - G. Housekeeping
 - H. Recreation
 - I. Hygiene
 - J. Garbage Handling

2. Practice

Each crewman will perform all operations and participate in the contingency procedures.

CRITERIA FOR
CERTIFICATION:

Attendance of lectures and participation in practice sessions.

COURSE AREA: Man/Systems Integration and Operation

COURSE TITLE: Support Functions

COURSE OBJECTIVE: To instruct the crewmen in the concepts and methodology of 90-day test goals, ground rules, and communication procedures

COURSE OUTLINE: 1. Classroom

A. Time Share Computer Link

B. Communications

C. Ground Rules

D. Mission Analysis

2. Practice

None

CRITERIA FOR
CERTIFICATION: Attendance at lectures and demonstrated grasp of support function concepts.

COURSE AREA: Man/Systems Integration and Operation

COURSE TITLE: Man/Systems Experiments

COURSE OBJECTIVE: To operate the test and measurement devices and achieve asymptotic performance levels on the psychomotor devices

COURSE OUTLINE: 1. Classroom

A. Light Measurements

B. Psycho-Acoustic Measurements

C. LRCCC

D. Human Describing Function

E. Rater

2. Practice

Each crewman will practice measurements and operate the psychomotor devices for the establishment of performance baselines.

CRITERIA FOR
CERTIFICATION:

Establishment of asymptotic performance levels and demonstrated proficiency in light and sound measurement

TABLE 1

SSS CREWMEN TRAINING CURRICULUM

BIOMEDICAL PROCEDURES	LIFE SUPPORT SYSTEMS (CONT)
• MICROBIOLOGY	• ATMOSPHERE CONTROL
• MEDICAL MONITORING	• TWO-GAS CONTROL
• BLOOD SAMPLING	• THERMAL CONTROL
• URINE SAMPLING	• CO ₂ CONCENTRATOR
• PHYSICAL FITNESS	• SABATIER/TOXIN UNIT
• EXPERIMENTS	• ELECTROLYSIS
LIFE SUPPORT SYSTEMS	• MASS BALANCE OPERATIONS
• WATER SUBSYSTEMS	MAN/SYSTEMS INTEGRATION AND OPERATION
• AIR EVAPORATOR	• HUMAN FACTORS
• WASH WATER	• SSS PROCEDURES
• VD-VF	• SUPPORT FUNCTIONS
• SAMPLING	• EXPERIMENTS
• COMTAMINATION	

Table 2

CREW PROFICIENCY RATING

STUDENT _____ INSTRUCTOR _____

COURSE _____ DATE COMPLETED _____

Skill Level (Highly Skilled, Skilled, Semi-Skilled) _____

Class Standing

1. _____ 5. _____

2. _____ 6. _____

3. _____ 7. _____

4. _____ 8. _____

Attitude (Enthusiastic, Attentive, Complacent)

Remarks: Cover special aptitude for maintenance and repair, knowledge of operational procedures and system.

Table 3
CREW COURSE RATING

STUDENT _____ INSTRUCTOR _____

COURSE _____ DATE COMPLETED _____

What skill level have you achieved through participation in this course:
(Highly skilled, skilled, semi-skilled)

How do you rate the class on skill level achieved?
(Enter names of all crew members including yourself)

1. _____	5. _____
2. _____	6. _____
3. _____	7. _____
4. _____	8. _____

How do you rate the performance of the instructor:

Knowledge of subject	Excellent, Good, Fair
Delivery	Excellent, Good, Fair
Compatibility with class	Excellent, Good, Fair

Remarks: Include recommendations for future course improvement and indicate areas in which you would like additional review.

TABLE 4
TRAINING INSTRUCTORS

BIOTECHNOLOGY AND RELATED EXPERIENCE (YR)	DEGREE	FIELD	BIOTECHNOLOGY AND RELATED EXPERIENCE (YR)	DEGREE	FIELD
12	BS	ME - LSS	14	MS, MD, MPH	MEDICINE, PHYSIOLOGY AND PREVENTIVE MEDICINE
8	MS	CHEM, E - LSS			
5	BS	ME - LSS	10	MA	PSYCHOLOGY
8	MS	CHEM, E - LSS	9	MA	PSYCHOLOGY
10	BS	ME - LSS	4	MA	PSYCHOLOGY
4	BS	ME - LSS	7	BS	ME - COMPUTER TECHNIQUES
2	MS	MICROBIOLOGY			
20	PhD	PHYSIOLOGY	1	PhD	PSYCHOLOGY
7	PhD	RADIOLOGY AND MEDICAL PHYSICS	9	BSMEE, MS	PSYCHOLOGY
			15	BS, MS	ME, MATHEMATICS
12	MS	MICROBIOLOGY	15	PhD	PSYCHOLOGY
8	BSEE, MD	MEDICINE AND EE	20	PhD	PSYCHOLOGY

200 MAN-YEARS TECHNICAL EXPERIENCE

18 ADVANCED DEGREES

9 TECHNICAL DISCIPLINES

BEHAVIORAL PROGRAM

By J.S. Seeman and M.V. McLean

McDonnell Douglas Astronautics Company

SUMMARY

The behavioral program assessed effects of confinement on crew behavior in the areas of psychological status, sleep durations, and task performance. Psychological status and sleep durations were measured by objective questionnaires. Task performance information was obtained by TV monitoring of the onboard crew. Psychologically, the test was not severely stressful as expected, but periods of low morale and mild hostility were noted. Certain tests appear somewhat insensitive and are candidates for exclusion from future studies. More subtle or sensitive tests must be developed in their stead. Sleep durations were significantly shorter during the early part of mission for crewmen on inverted sleep cycle and adaptation did not occur until approximately the mid point in the test. Task performance information indicates a relatively poor use of the crew in terms of work performance.

BACKGROUND

A great deal of research has recently been directed toward determining individual and group reactions to isolation and confinement. Findings common to most of these studies have included: manifestations of boredom and monotony, declines in morale, interpersonal problems, great individual self-control to contain hostilities, scapegoating on outside personnel, impairment of memory, and low energy for intellectual pursuits with little or no loss in intellectual ability. (For more detail in this area, see Appendix A.) To the extent that one or more of these similar developments manifest themselves during an orbital or deep space mission, the efficiency and effectiveness of crew may be compromised. The research reported herein is one attempt to obviate such an occurrence.

OBJECTIVE

The objective of this sub-program was to assess the effects of confinement on crew behavior.

PROCEDURE

During the 90-day test various tests were taken by the crew at scheduled times. The tests were self-administered and answered via an onboard computer keyboard. One category of test consisted of those which were considered to avail the outside staff of timely information concerning crew status and were available for real-time analysis. The other category consisted of tests that were available for post-test analysis only. Both categories are listed in Appendix B. Only group mean scores are reported.

Task performance was determined by continuous TV monitoring and the logging of start and stop times for crew activities. This area is fully covered in the mission activity analysis (paper no. 24 of this symposium) and will not be detailed here.

RESULTS

All the resultant data show a great deal of consistency. Decreases in positive affect are generally supported by increases in negative affect. Plotting the primary affect scale (PAS) as a positive and negative dichotomy shows a clearly significant drop in positive affect that reaches a low on day 59 and increased moderately thereafter (fig. 1). This curve is generally followed by corresponding increases and decreases in the negative affect curve. A spike, however, in positive affect occurred on day 52 that is not supported by a corresponding decrease in negative affect.

Subjective stress (plotted in the same figure) began with an initial high and then dropped to a very low level. A moderate rise occurred during days 45 through 75 which is in agreement with the PAS results.

The isolation symptomatology questionnaire (ISQ) results are apparently less sensitive (no statistical tests have been applied yet) than PAS or the stress scale, but trends are still apparent in the graph. These data were dichotomized into positive and negative categories and the resulting plots show a slight downward trend in the positive factors. An upward fluctuation in the negative factors occurs about day 65, and is followed by a downward trend on day 85. The PAS, stress scale, and ISQ were combined into one plot as they all purport to measure individually oriented effects.

The group confinement inventory (GCI) shows plots similar in trend and apparent sensitivity to the ISQ. The positive scale decreases moderately about the third quarter of the mission and subsequently rises during the last quarter. The negative scale shows a slight increase through the third quarter and then displays a plateau.

Intercrew hostility, as measured by the hostility scale, peaked around day 16 (a result supported by the stress scale) and decreased to a rough plateau by day 30. Hostility directed toward outside personnel peaked at day 32 and decreased to approximate the intercrew hostility plateau by day 45. GCI plots and the two hostility scale plots are shown together as they are socially directed tests (fig. 2).

The sleep data, in terms of variability and duration, indicate that crewmen 3 and 4 on the inverted sleep cycle did not achieve complete adaptation until nearly the middle of the test (fig. 3). Group reported sleep time is shown in figure 4.

The descriptive sentence test did not indicate any deterioration in cognitive functioning.

Task performance was divided into categories of: (1) operational tasks, (2) meals, (3) free time, and (4) sleep. Sampling over 23 days (not always consecutive) revealed that 14 percent of crew time was spent on operational tasks, 9 percent on meals, 37 percent free time, and 37 percent on Sleep (see fig. 5 and table 1). Figure 5 shows an apparent trend in free time increase from midpoint of the test until just beyond the two-thirds point when a reversal is noted.

Hostility and stress measured on the outside personnel, i. e., persons in contact with the crew, was very low level and showed no significant fluctuations.

Appendix A supports the position that the 90-day test was an adequate simulation of an operational mission by providing indirect evidence that crew behavioral changes seen during the test were different only by degree from those seen under operational conditions.

CONCLUSIONS

The overall low-level scores in the negative test categories and the stress scale indicate that the test was not perceived as stressful by the crew. Whereas the mission may not have been stressful, neither was it a happy or pleasurable experience for the crewmen.

Reported intercrew hostility was generally quite low, but isolated incidents were observed that were evidently not reflected in the hostility scale. This may have been an attempt by the crewmen to avoid negative references to one another.

All the data point to a definite slump in crew morale from approximately day 45 through day 75. This finding is supported by diary entries and outside observations. The spike in positive affect noted on day 52 PAS results is somewhat inexplicable but may be the result of:

- A. Completing the half-way point in the mission.
- B. Increased crew social interaction on that day.
- C. Highest crew mean sleep time occurred in the sleep period immediately before the test.
- D. Spurious data not supported by other tests.
- E. A real increase in positive affect for unknown reasons.

Insofar as hostility toward the outside personnel was concerned, it was minimal and never became a problem. By the same token, stress and hostility in the outside personnel was negligible and displayed no apparent relationship between the occurrence of stress or hostility onboard.

Interestingly, there was more hostility shown toward the sound level in the equipment compartment than toward members of the study. Also the equipment compartment sound level was measurably more annoying than that in the crew compartment.

Certain behavioral tests (ISQ and GCI) may be insensitive to the low levels of stress inherent in the SSS. Unless additional information comes to light which denies this conclusion, these tests are prime candidates for elimination from future batteries.

The suggestion that crewmen may have consciously biased behavioral test scores on at least the hostility scale (corroborated by post-test debriefings) indicates that the validity of these devices for assessing affect states of individual crewmen is highly suspect. This conclusion points out the desirability of increased effort to develop valid techniques for the measurement of affect states.

The crew reported its primary difficulty resulting in boredom was the inadequacy of the work program. This inadequacy resulted in an overall use of crewmen for approximately 1,200 man-hours of work out of a total of 8,600 man-hours of time during which work could have been accomplished. This is an approximate 14 percent utilization of the crew for mission-related tasks. As time progressed during the test and as subsystem difficulties were resolved, free time available to crewmen increased and work-related activities decreased (fig. 4). This is probably not unlike what would be expected on an actual mission in terms of utilization of time by crewmen over the mission duration. A point to be made here is that almost without exception all crewmen felt that more could have been accomplished in terms of work performance on board had there been more to accomplish. As with most group

confinement studies, inactivity or free time not devoted to productive mission-related work may be considered anathema and the primary problem to overcome in successfully scheduling activities of crewmen for long-duration confinement situations.

During debriefings the crew expressed a desire for more responsibility to reside onboard in running the mission. This is particularly true in regard to the role of the Crew Commander. The role of the Crew Commander apparently was not satisfactorily defined before the mission. Consequently, the Crew Commander was uncertain about his responsibilities and authority on-board. This uncertainty affected his effectiveness to no small extent.

Behavioral results are considered sufficiently accurate to be employed in the prediction of human behavior under operational mission conditions. This conclusion is based upon the findings reported in Appendix A.

Unfortunately, the minimal behavioral effects noted during this 90-day test do not provide sufficient information to permit extrapolation to missions of greater duration. Similarly, information based upon a group of four provides little data for the prediction of behavior of groups consisting of more than four crewmen.

Appendix A

MISSION SIMULATION FIDELITY

In a recent review of the effects of confinement and isolation upon small groups, Smith* reports the following findings relevant to our study: "In contrast with findings from studies of individuals isolated alone, groups in confinement report far fewer unusual sensory experiences, perceptual distortions, unusual dreams, and etc. Confined groups, however, often face very difficult inter-personal problems, and particularly in lengthy confinement, may experience tedious boredom due to the unchanging environment."

- A. "As well documented as any finding in the group confinement literature is sizeable presence of irritability, hostility, and personality conflicts, although often, to avoid alienation of the group, persons made great efforts towards self control (sic). These inter-personal problems have been shown to be more serious among groups, who, by personality composition, could be expected to be incompatible. Highlighting the importance of group compatibility for confinement, incompatible groups are also under more stress and report more symptomatology than do compatible groupings. Members of confined groups tend to withdraw from one another and from group activities more and more as lengthy confinement drags on. They also display increased territoriality for areas and for positions, perhaps in their quest for privacy."
- B. "Relationships with those outside of confinement are subject to change as well. Much of the aggressive hostility that is observed is frequently directed away from the group, perhaps representing useful scapegoating. There is speculation that the loss of meaningful and relevant feedback from the parent society may be a problem, particularly in very lengthy and isolated confinement."
- C. "There are several reactions to group confinement that are frequently stated. In lengthy confinement, boredom and monotony are characteristically mentioned even when facilities are available to alleviate the problem. For some groups morale and general motivation remain at acceptable levels, but pronounced declines are frequently in evidence and there are no reported instances of consistent morale increases over time."
- D. "Many things serve to annoy members of confined groups. These annoyances frequently center around crowded conditions, inter-personal problems, food, difficulties of maintaining cleanliness, and environmental factors such as noise and odors."

*Smith, Seward, Studies of Small Groups in Confinement, in Sensory Deprivation: Fifteen Years of Research; Zubeck (ed.) Appleton-Century-Crofts, N.Y. 1969

- E. "Most of the reported symptomatology focuses on sleeplessness, depression, general mood declines, compulsive behavior and psychosomatic problems. It appears as if holding back overt expression of irritation and hostility leads to frequent instances of headaches and other psychosomatic complaints."
- F. "Performance measures have been employed in many studies. As a rule, neither intellectual effectiveness nor perceptual-motor ability shows any consistent change of note during short-term confinement. The picture is not so clear for very lengthy durations, such as is characteristic of wintering over in the Antarctic. Impairment of memory, difficulty in concentrating, low energy for intellectual pursuit, and less team performance effectiveness are often reported. So far test data are lacking to substantiate many of these feelings."

The final test of the adequacy of mission simulation seems to be the degree to which phenomena usually found under conditions of confinement have occurred during the mission in question. The phenomena reported below derive from debriefings and observations accomplished during the test. Comparing the findings concerning our test crew with findings of Smith's review, we see the following corresponding similarities and differences:

- A. Only one crewman reported unusual dreams. Another crewman reported an isolated incident of an apparent perceptual distortion in which he reportedly saw things out of the corner of his eye which were not really there. This may have been related to that particular crewman's level of fatigue at that moment. Three out of four crewmen reported problems with boredom due to the unchanging environment, especially as the two-thirds point of the mission approached.
- B. Although irritability, interpersonal hostility, and personality conflicts did occur during our mission, they could not be described as sizable. Most crewmen, reported making great efforts toward self control. This self control was referred to by the crewmen as an attitude of professionalism. If interpersonal problems are more serious among groups who by personality composition could be expected to be incompatible, then there is no other alternative than to conclude that incompatibility among personality characteristics of our crew members was minimal. Throughout the mission the crew tended to withdraw from one another. At times, interactions were not existent; even with concurrent physical proximity. Some evidence exists that territoriality for areas, in our case subsystems, and for possessions took place. This was not a prominent aspect of the mission.

- C. Though unreported by communication monitors, principal investigators, or others who came into audio contact with the crew, post-test findings reveal that some communication monitors were used by some crewmen as scapegoats for hostilities. Although not a prominent feature of the relationship between onboard crew and the outside crew the fact remains that these incidents were reported by the crewmen.
- D. Although general motivation of the crew remained at an acceptable level, a trend toward decline was in evidence through the two-thirds point in our mission when a reversal apparently took place. Only one data point of the many taken through the mission supports the conclusion that morale may have improved at any time during the mission. This was at the day 52 point and is discussed in the behavioral findings as a possible elevation in affect as a consequence of having accomplished 50 percent of the mission. Otherwise, mood generally declined.
- E. Crowded conditions, food, and environmental factors such as noise and odors were not a prominent source of annoyance for the crew. Difficulties in interpersonal relationships and in maintaining body cleanliness were mentioned after the test. Never was the annoyance at such a level that crewmen felt obliged to express their annoyance to program management personnel.
- F. On a group basis, sleeplessness, depression, compulsive behavior, and psychosomatic problems were not characteristic of this crew. Individual crewmen did display occasional behavior indicative of depression, compulsivity, and psychosomatic problems. If the holding back of overt expressions of irrationality and hostility leads to increased frequencies of complaints, then we are left with the conclusion that the degree of such withholding of expression, as a consequence of the overall degree of irritation, was minor.
- G. Performance measures employed during the test displayed no consistent deterioration. The one performance measure (LRC-CC) employed by all four crewmen throughout the 90 days, three times a day for 100 trials each time, showed a continuous learning curve. Two crewmen report a decreasing desire to engage in intellectual pursuits over time, one reported impairments of memory and thought. None reported significant difficulties in concentration, but the impression of team performance effectiveness deteriorating over time is substantiated by post-test reports.

Appendix B

TEST USED

The following tests available in real time:

- A. Hostility Tests - measures mood on a continuum from pleasure to hostility
 - 1. Inter/onboard crew
 - 2. Inter/outside personnel
 - 3. Toward outside personnel
 - 4. Toward onboard personnel
 - 5. Toward acoustic environments in crew and equipment departments
- B. Subjective Stress Scale - measures subjectively perceived stress on a continuum from none to incapacitating.
 - 1. Onboard crew
 - 2. Outside personnel
- C. Descriptive Sentence Test - assesses cognitive functioning (reasoning). Onboard crew.
- D. Sociometry - assesses changes in sociometric preferences (group structure). Onboard crew.
- E. Sleep Questionnaire - assesses quantitative aspects of sleep. Onboard crew.

The following tests available post test:

- A. Isolation Symptomatology Questionnaire - assesses effects of confinement on the individual. Onboard crew.
- B. Group Confinement Inventory - assesses effects of confinement on the individual as he relates to the group. Onboard crew.
- C. Primary Affect Scale - assesses qualitative aspects of affect or feelings. Onboard crew.

TABLE 1

MANPOWER UTILIZATION -- 90-DAY VALUES

CREW SIZE	AVAILABILITY	MISSION DURATION	TOTAL AVAILABLE MAN-HOURS
4	24 HR/DAY	90 DAYS	8,640

UTILIZATION CATEGORY	MAN-HOURS EXPENDED	MEAN DAILY EXPENDITURE (HR)	MEAN PERCENTAGE DAILY UTILIZATION
OPERATIONAL TASKS	1,224	3.4	14
MEALS	756	2.1	9
FREE	3,204	8.9	37
SLEEP	3,168	8.8	37
MISCELLANEOUS AND UNACCOUNTED	288	0.8	3
TOTAL	8,640	24.0	100

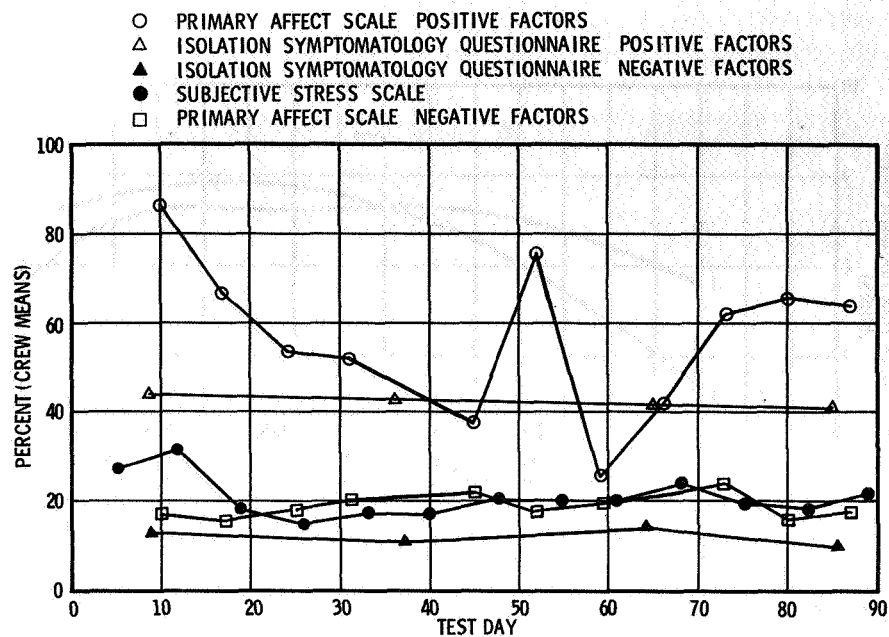


Figure 1.- Trends in personally oriented affect.

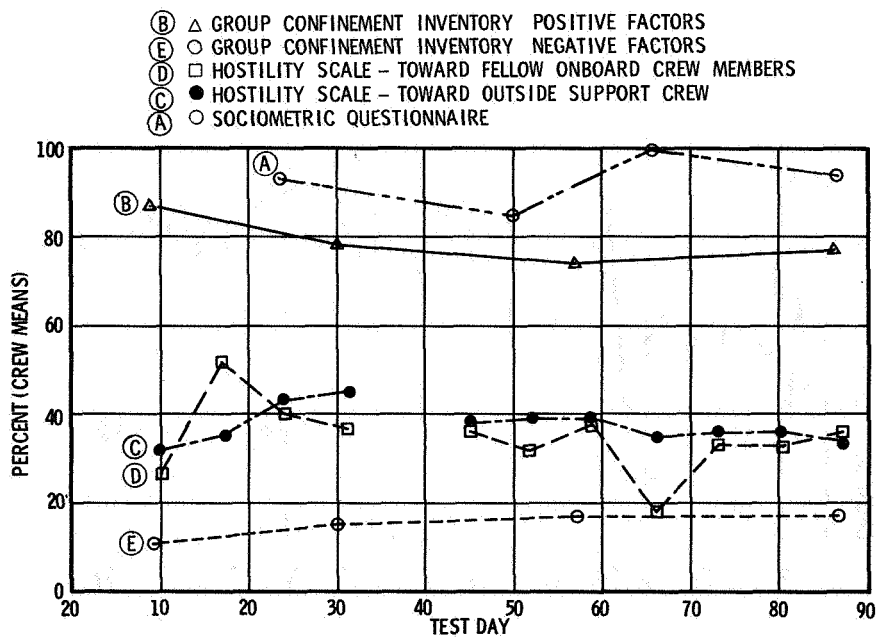


Figure 2.- Trends in group oriented affect.

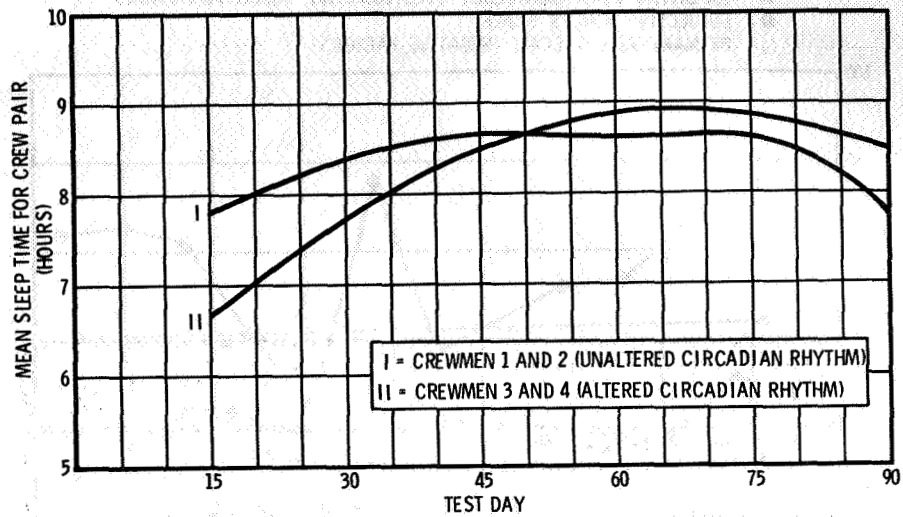


Figure 3.- Sleep questionnaire responses. (Smoothed curve based on 15-day segments.)

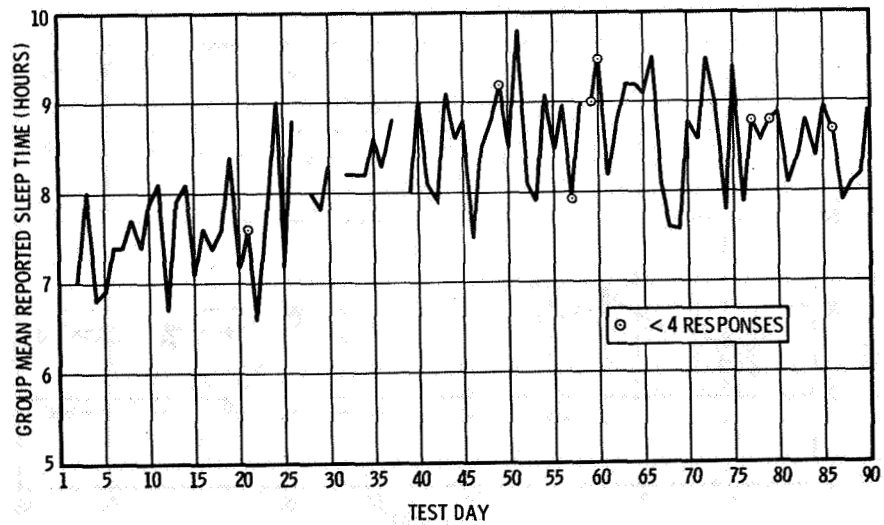


Figure 4.- Reported sleep time.

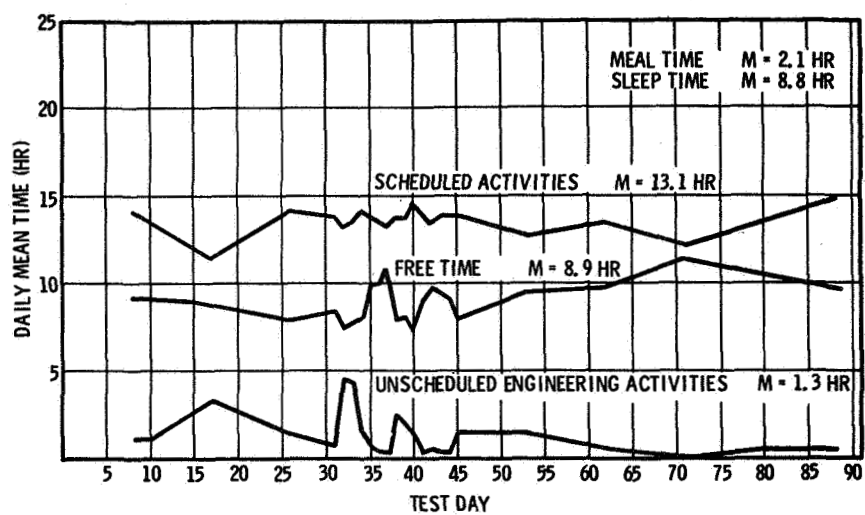


Figure 5.- Crew time utilization (23 selected test days only).

MANNED MISSION ACTIVITY ANALYSIS

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SUMMARY

The objectives of the Mission Activity Analysis (MAA) experiment on the 90-day test were to generate manual and computer schedules of planned crew activities for the purposes of

- (1) Evaluating the planning and scheduling capabilities of the LRC Space Station Mission Simulation Mathematical Model (SSMM)
- (2) Comparing crew performance data with manual and computer-generated crew activity schedules

The experiment objectives were successfully accomplished. The MAA experiment crew event descriptions and scheduling activity acted as a forcing function for the early identification of problem areas and operational constraints.

The MAA crew activity schedule provided direct and material support to the successful operations conducted during the test.

INTRODUCTION

The extensive manual planning effort expended on space flights has been most effective as evidenced by the success of missions to date. However, the increased emphasis on spacecraft utility, coupled with increased mission complexity, crew size, and the pressing requirement for early selection of the most cost effective system to insure completion of the maximum number of mission objectives, has resulted in the design of a number of planning and simulation computer models to support program planners. One such model, the Langley Space Station Mission Simulation Mathematical Model (SSMM), is an integrated set of 11 computer programs which provides the capability for in-depth space station program planning (fig. 1). The many interrelated space station elements, such as crew skills, human factors, station capabilities, experiment programs, and station operations and logistics, are considered in their proper perspective and the interacting effects of these variables are analyzed with respect to their effectiveness on the total mission. The 90-day manned test of a Regenerative Life Support System with the McDonnell Douglas Space Station Simulator (SSS) as the space vehicle provided an excellent opportunity to evaluate the planning and scheduling capabilities of the SSMM and to compare actual crew performance data with manual and computer-generated crew activity schedules.

PROGRAM DESCRIPTION

Mission Activity Analysis was accomplished through mutually supporting but independent efforts; McDonnell Douglas Astronautics Company (MDAC) employed manual planning and scheduling techniques and computer schedules were generated at Langley. Although it will be possible to cover only the more significant areas required for the accomplishment of this effort, it is considered of some importance that they be presented in sequence to provide a better understanding of "mutually supporting but independent efforts."

Definition of Data Submittal Format

LRC designed the data submittal format for the crew skill matrix (table I) and crew events matrix (table II) to ensure that all essential data items were provided for adequate exercise of the planning and scheduling capability of the SSMM. The formats were coordinated with MDAC to ensure that they would allow the inclusion of all test and operational constraints and provide an easily understood and usable method of presenting the data.

Collection and Formatting of Crew Events Data

The initial collection and formatting of the crew events data was accomplished by MDAC by using the traditional methods required during the initial planning stage of any program, by analyzing system and experiment descriptions, and by interviewing engineers and experimenters. At the time of the initial effort, final selection of all systems and experiments had not been made. Therefore, the first iteration of the crew events matrix described only 50 events, some incompletely and all with conservative time estimates. There were three major revisions to the matrix which reflected the inclusion of refined data with retention of the conservative time estimates. The final iteration resulted in 87 events. The crew events matrix constituted a standard data base used by both LRC and MDAC for computer and manual planning and crew activity scheduling.

Formulation of Mission Event Profile

In the initial scheduling effort, crew activities for the entire 90 days were set up on a day-by-day basis to formulate the mission events profile shown in table III. This profile was generated at the LRC by using the Planning Model Routine of the SSMM (fig. 1) to indicate the events which were to be active on each mission day.

The generation of this profile by the computer model provided a basis on which to evaluate the model capability for long-term scheduling. It also eliminated the need to spend the extensive time required to manually generate the mission events profile. This schedule was updated by MDAC as events were added to or deleted from the crew events matrix and it was the key document, when supplemented by details in the crew events matrix, used in crew activity scheduling.

Formulation of Crew Activity Schedules

Crew activity schedules, consisting of 270 pages of 8-hour mission segments, were formulated on an independent basis by LRC and MDAC with the following items as standards: (1) mission events profile, (2) crew events matrix, (3) mission rules, (4) crew operating ground rules, and (5) given work/rest cycles for each crewman (figs. 2 and 3). The work-rest doctrine of two up and two down was selected to ensure crew safety and provide the best coverage of development-type EC/LS (environmental control/life support) equipment. Allowance was also made, as much as practical, for crew preferences in the ordering of tasks. The primary guide used for the MAA scheduling effort was to provide for flexibility in performance of unscheduled tasks without the necessity for disrupting the normal schedule. The crew activity schedules were intended as a guide and reference for necessary tasks to be conducted. The crew was at liberty to deviate from these schedules for any "non-time-critical" event.

The manual formulation and subsequent revision of schedules was a difficult and time-consuming task. Each of the three major updates of the crew events matrix contained numerous changes which necessitated a major update of the mission events profile and a complete revision of the crew activity schedule. The large man hour effort required in this activity indicated the necessity for good planning and scheduling aids.

The SSMM formulation of crew activity schedules at LRC essentially paralleled the manual effort. The initial baseline case for computer scheduling in which all activity, system, and crew parameters were formatted for computer input was the largest single step in the Langley effort. The first schedules produced by the model necessitated a revision of model output into a more readily usable format and pointed up some problem areas in the methods for handling the operational constraints involved. The problems were largely solved by the use of the SSMM capabilities for setting up fixed times, priority assignments, common equipment checks, and predecessor-successor event chains and by a program revision of plotted output. This resulted in a well-sequenced schedule in a format acceptable to operationally oriented personnel.

Computer schedules were periodically updated to evaluate the SSMM capability for rapid generation of new schedules. Before test start, these iterations were based on updated events information obtained from revisions of the crew events matrix. During the test, activity changes were based on interviews with the Crew Commander and analysis of daily monitor logs. Crew activity schedules for days 31 through 50 were provided to MDAC by Langley. Iterations and reissue of computer schedules was, on an average, more than one order of magnitude faster than the same changes made by manual methods.

Training

The Mission Analysis Activity training consisted of 1 hour for all crew members during which the purpose of MAA was discussed in detail. An additional 2 hours were spent in review of the 90-day crew activity schedule during which the crew verified crew constraints for scheduling a body wash after exercise, a shave before breakfast, a free time period in conjunction with dinners, and a

minimum of 1-hour time lapse between meals and exercise. During the 5-day manned test and during the first 15 days of the 90-day manned test, the MAA monitors received on-the-job training. Instruction was given to each crewman during an early duty shift to ensure he understood the written instructions for monitoring, logging of data, and operation of the time-lapse video system.

Test Monitoring

Data for this experiment were collected for days 31 through 60. The four backup crewmen performed duty as MAA monitors. Continuous surveillance of the crew was maintained by means of closed-circuit television monitors. A log entry was made to record the start and stop time of each event and a time-lapse video system was used to record a picture each 3 seconds from one of five cameras within the simulator. The MAA monitor was assisted by the communications monitor.

Data Analysis and Report

Data analysis is presently in process and therefore only preliminary results are presented in this paper. For each of the 10 test days selected for comparison, a detailed analysis was made of the mission analysis monitor's log to construct a graphic presentation of actual crew performance (fig. 4). The log information was supplemented by review of video time-lapse recordings, on-board diary entries, and noninterference performance data. This information was then loaded for computer program manipulation to provide a listing by day for each crewman of total scheduled time, total free time, total time for unscheduled engineering events, and total time for unscheduled nonengineering events. An analysis of each event performed showed the delta of starting time as a function of scheduled starting times for each. A summary of these data for days 31 and 45 (Mondays) is presented in the following table:

Day	MDAC schedule		Actual crew time, hr:min			Computer schedule	
	Scheduled time, hr:min	Free time, hr:min	Scheduled	Unscheduled	Free	Scheduled time, hr:min	Free time, hr:min
31	62:45	33:15	54:31	5:49	35:40	61:05	34:55
45	64:45	31:15	58:31	7:10	30:19	67:15	28:45

The three basic elements of the table are defined as follows:

(1) Scheduled events include baseline medical and manned systems events, station operations events, scheduled maintenance of SSS and experiment equipment, meals, sleep, experiment events, and personal hygiene (shave and body wash only).

(2) Unscheduled events include unscheduled maintenance and repair of SSS and experiment equipment, crew response to staff requests for monitor or adjustment of equipment, interviews, and unscheduled medical events.

(3) Free time in the MDAC and computer schedules is the time for recreation and all unscheduled events; in the crew performance schedule it is the time for recreation.

Comparison of the manual schedule times and performance times in the table shows that on day 31 the crew spent 8 hours and 14 minutes less on scheduled events than planned (approximately 2 hours per man). Of this time, 5 hours and 49 minutes were spent on performance of unscheduled events and the remainder on free time. The time used for unscheduled events and the increased free time period resulted from a reduction in scheduled event time rather than from a reduction of free time as originally envisioned by planners. This is due partly because the schedule event times were conservative estimates and partly because of the crew decision to reduce scheduled event times to allow for necessary unscheduled engineering tasks. For example, on day 31 approximately 48 percent of the time saved resulted from a reduction in use of time scheduled for meals, 10 percent of time saved from scheduled exercise events, and the remainder of 42 percent from all other events. On day 45, the percentages are 70 percent, 12 percent, and 18 percent, respectively. Most of the differences result from the time used for meals on each of the 2 days. The majority of the estimated times allocated in events were, in fact, fairly accurate. During this phase of the mission, the crew by choice limited time for meals when in their opinion it was important to spend the time in pursuit of more productive matters. An event-by-event comparison to establish specific reasons for differences between schedules and crew performance is yet to be completed for the remaining 8 days of the 10 selected for comparison.

Figure 5 shows a plot of the average hours per crewman in each of the previously mentioned categories of scheduled events, free time, and unscheduled events. It can be seen from this figure that differences between the activities scheduled and actual work time are relatively small. The free time spent on unscheduled engineering tasks, such as equipment repair, accounts for most of this difference. The detailed analysis of all 10 days will show exactly where the crew time for unscheduled maintenance was acquired. Analyses of this type are also extremely useful as a cross-check of selected basic engineering data. For example, in the 10 days shown in this figure, the available time per day per man utilized for unscheduled equipment maintenance was 1.5 hours. This average includes 2 days (32 and 33) of heavy maintenance requirements, and correlation of the MAA data with engineering data on vacuum-distillation-vapor-filtration boiler replacement confirmed this fact.

CONCLUSIONS

The Mission Activity Analysis objectives of evaluating the planning and scheduling capabilities of the SSMM and of providing scheduling support to the 90-day manned test were successfully met. The Planning Model's mission event

profile accurately reflected the requirements and constraints contained in the crew events matrix and was one of the key tools used in manual planning and formulation of the daily crew activity schedule. The mission simulation model successfully sequenced daily events into crew activity schedules that were operationally acceptable. The rapid generation of new schedules by the SSMM during the test proved its capability to update as needed. For example, a response to an operational request to delay sleep start times for crewmen 3 and 4 for 1 hour demonstrated the model's capability to support a real-time request in that daily crew activity schedules for a 7-day period were run and recommendations returned to the Test Program Director within 24 hours. Some desirable modifications, such as faster input capability and improved methods for handling operational constraints, to further increase and improve model capabilities have been identified as a result of the experiment.

The LRC designed data submittal format for the crew events matrix requires operational personnel to perform a partial task analysis of all events in which the crew will participate and further requires an early definition of mission constraints. It provides a requirement for operational personnel to describe in their own language the input data and operational constraints necessary for crew activity scheduling by manual methods or by use of the SSMM.

The manpower and time allocated for data collection and formatting of crew events data were inadequate for a development-type test in which change is required up to test start to maximize the number of test objectives that can be met.

Neither the time-lapse video tape nor the MAA monitor's log was adequate for recording data and the use of the two together was marginally adequate for this experiment. The time-lapse system can record only one area of the chamber at a time and crew event identification is frequently difficult. An 8-hour shift for MAA monitors was too long a period of time for the monitors to provide continuous attention to crew activity. Numerous errors were noted in the manual logs after the fifth hour of shift duty. Also, the monitor could not effectively observe and log the activities when all four crewmen were up at one time. The diversity of activities in different areas of the simulator did not permit total coverage.

RECOMMENDATIONS

The LRC designed data submittal format for the crew activities matrix should be employed in any future manned simulation tests. Further, it should be considered for use in crew activity scheduling for manned flights since it serves as a forcing function to perform a detailed analysis of crew activities and provides for the early definition of mission constraints.

Any future manned development test should provide for a task analysis early in the program to insure realistic event time estimates, crew procedures, and, equally important, a means of identifying those key factors in crew events which can be used as a measure of performance.

Although the schedules used were acceptable, on future manned missions of longer duration with dynamic experiment programs a more easily handled crew activities schedule should be provided to be used in conjunction with a capability for updating onboard schedules on an as-needed basis to eliminate the necessity for prescheduling the entire mission.

Prior to future manned tests, a study effort should be conducted to define a more effective method for monitoring and logging of crew activities.

Manual and Space Station Model activity schedules were both operationally acceptable in event sequencing for the 90-day test. Since the computer has a marked advantage in the time required to generate and update activity schedules, future manned tests should use, whenever possible, computer-generated crew activity schedules which have been reviewed and approved.

It is most important that the present philosophy be maintained; that is, the crew activity schedule is a management tool and should provide as much flexibility as possible to permit continuous attention to unscheduled requirements without disruption of the remaining schedule for the day.

TABLE I.- CREW SKILL MATRIX

Skill	Crewman			
	1	2	3	4
Mechanics	2	2	1	1
Electrical/electronics	2	1	2	1
Microbiology	1	1	2	2
Biochemistry	1	1	2	2
Medical treatment	2	2	2	2
Photography	1	1	1	1
Utility	1	1	1	1
Special, requires crewman 1	1	0	0	0
Special, requires crewman 2	0	1	0	0
Special, requires crewman 3	0	0	1	0
Special, requires crewman 4	0	0	0	1

Notation:

- 1 Primary skill
- 2 Secondary skill
- 0 No skill

TABLE II.- CREW EVENTS MATRIX

Event	Event title	Frequency	Crew skill	Crew time	Equipment	Preevent restriction	Postevent restriction	Power	Work area	Remarks
M5	Biomedical checks	1/day/crewman	CM	15 min/ 2 crewmen	-----	M43, sleep	---	----	2	2 man event: Schedule immediately after sleep period per requirement of medical director.
M53	Nose and throat swabs	1/week/crewman	CM	10 min/ 2 crewmen	-----	-----	---	----	2	2 man event: Schedule on Tuesday prior to pass out, M42.
RL1	Cabin cleaning	2/week	7	30 min	Vacuum	-----	---	600 W	1, 2, 3, 4	Crewmen will rotate duty at their discretion. Schedule when all crewmen are up.
M93	Garbage can check	1/week on Sunday	7	10 min	-----	-----	---	----	4	If cans bulge, pass out on Tuesday
M51	Mass balance data reporting	1/day	10	15 min	TSOL	-----	---	----	1	Schedule between 2000 and 0600 hours. Computer use limited to these hours.
M29	LRC psychomotor test	3/day/crewman early, middle, and late shift	CM	10 min	Psych. tester comm system	-----	---	----	1	Schedule 130 min same time each day per experiment protocol. Do not schedule concurrently with R39 and R24 due to outside staff-support limitation.

TEST DAY

[illegible]

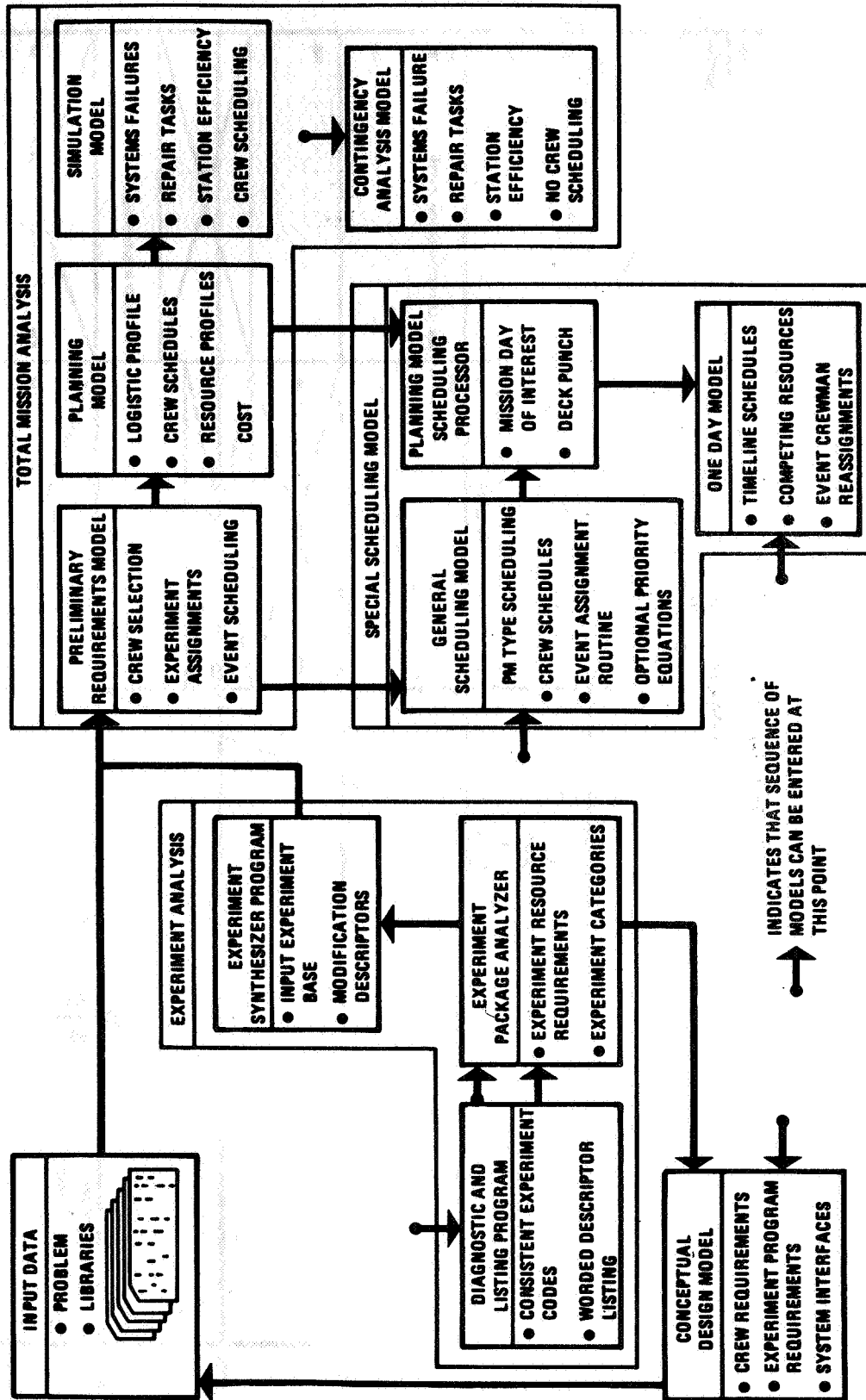


Figure 1.- LRC model concept and utilization sequence.

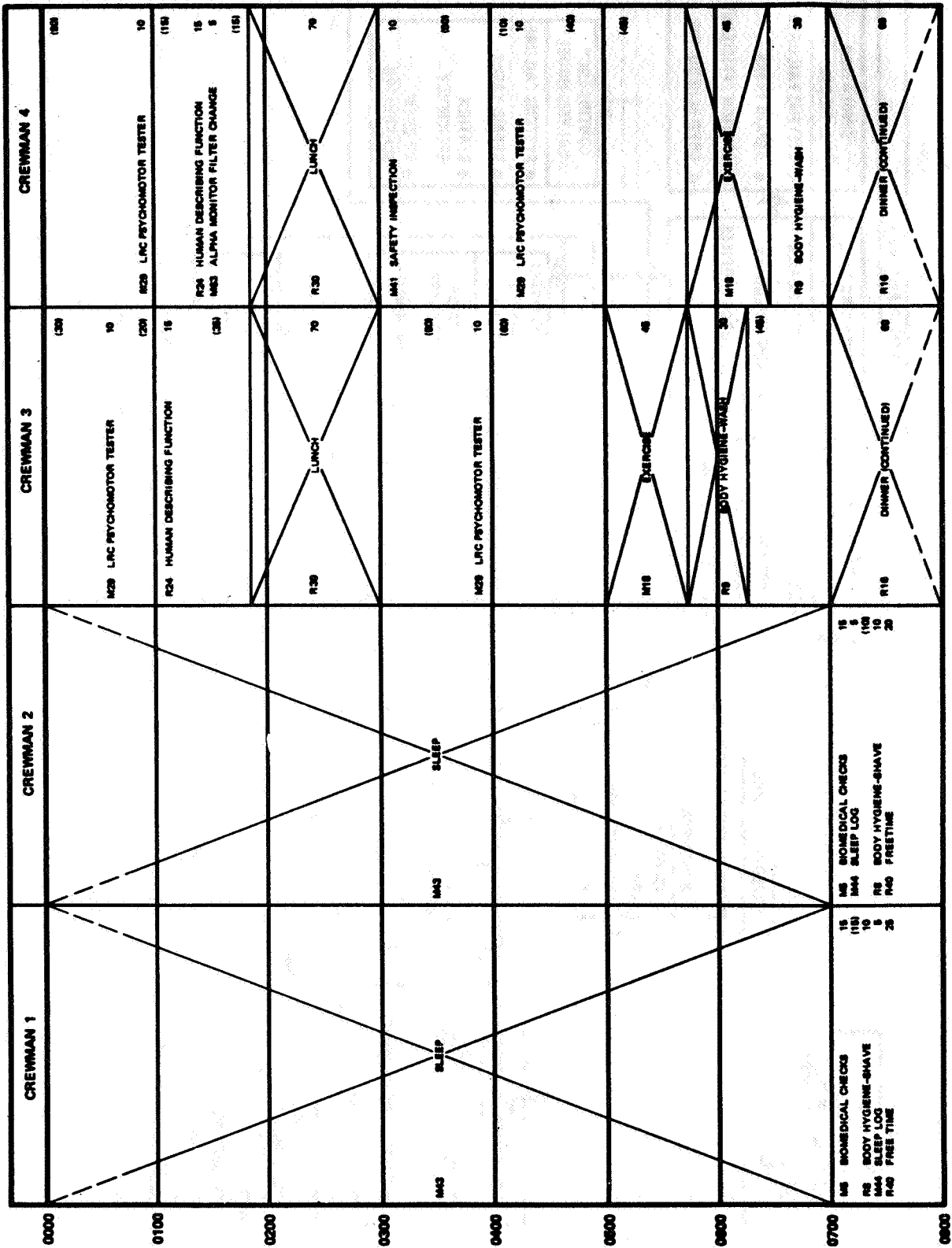


Figure 2.- Day no. 45 MDAC activity schedule.

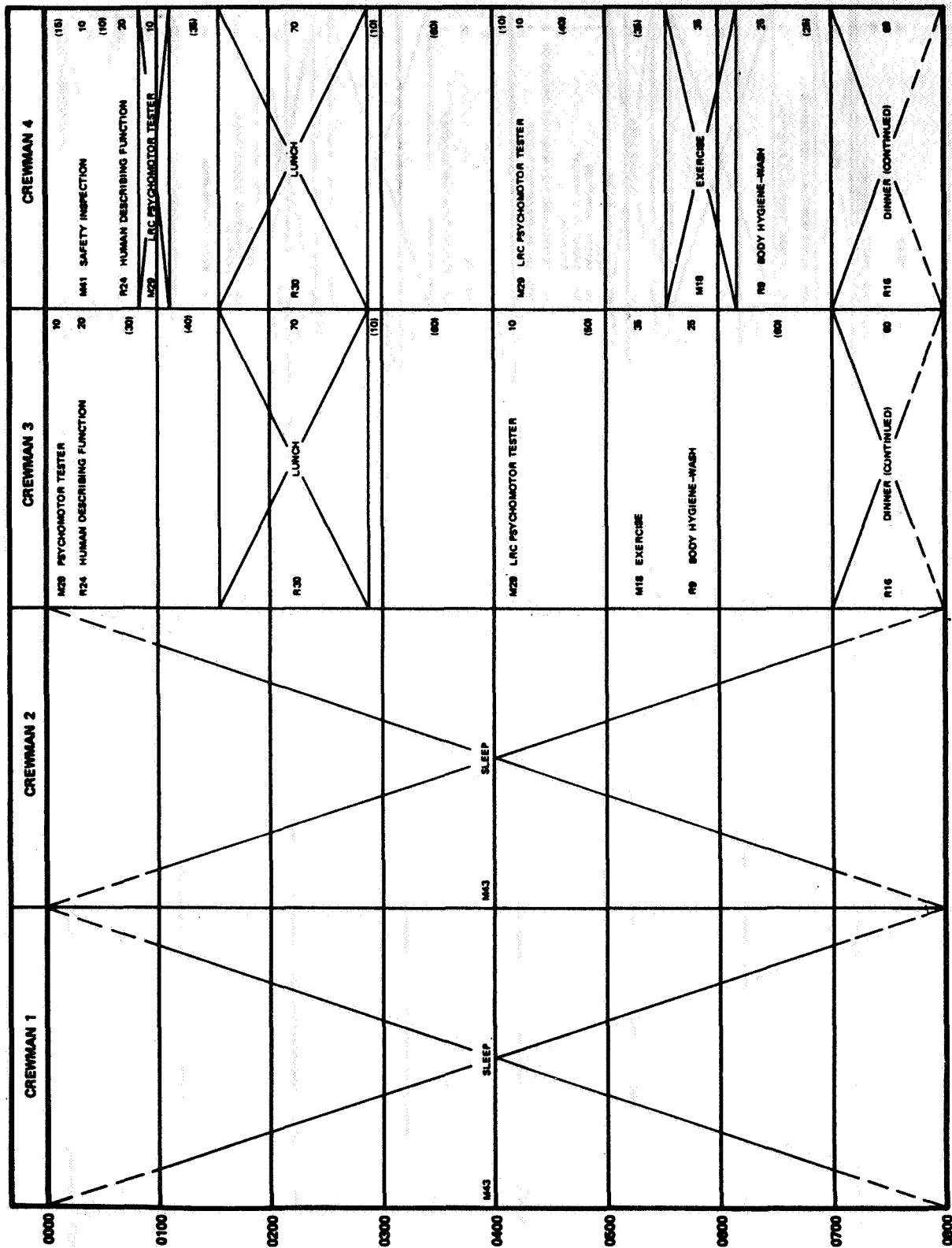


Figure 3.- Day no. 45 computer activity schedule.

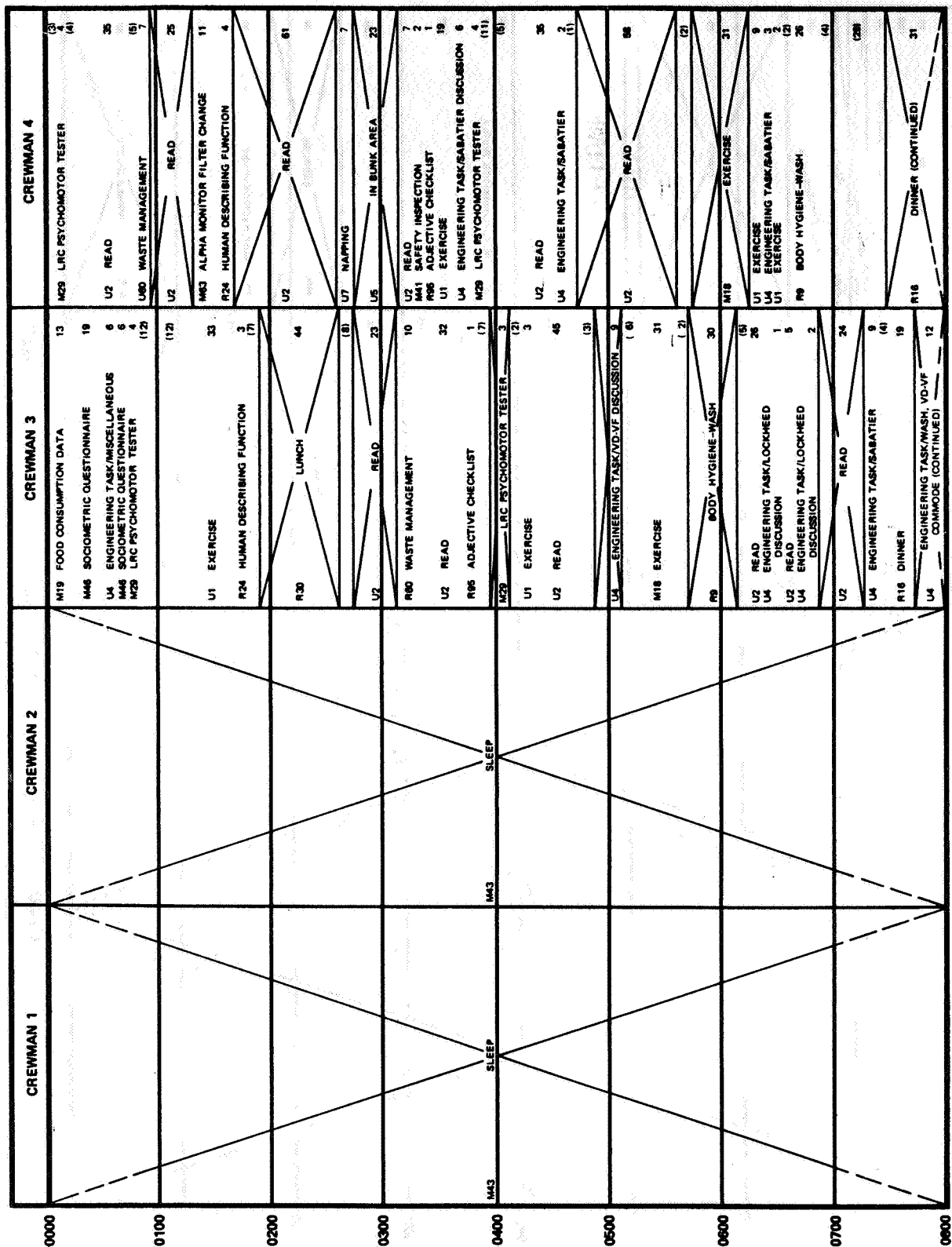


Figure 4.- Day no. 45 actual crew schedule.

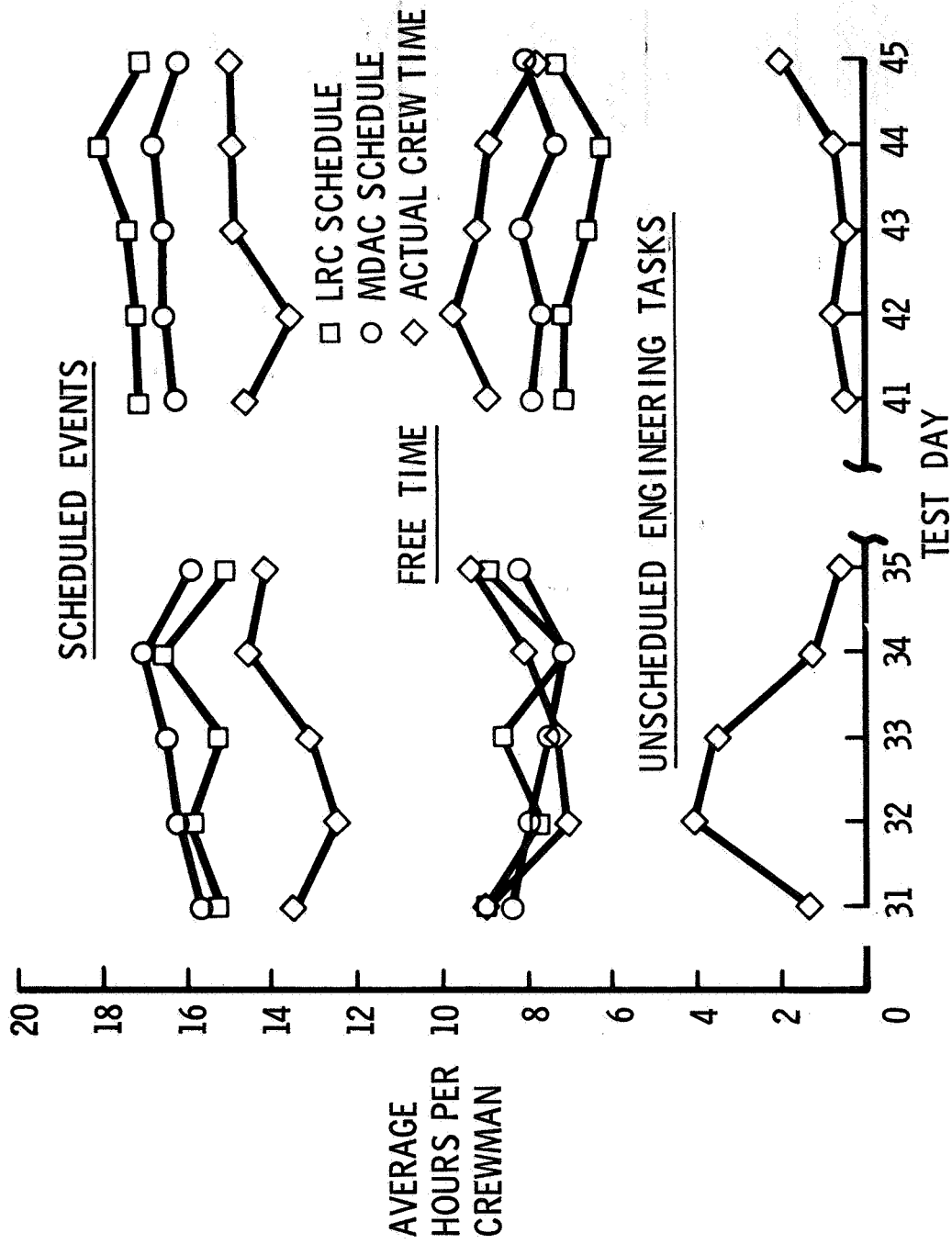


Figure 5.- Crew activity schedule analysis.

HABITABILITY

By J. S. Seeman, R. V. Singer, and M. V. McLean

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SUMMARY

An overview is provided of the more outstanding findings regarding crew reaction to the environment afforded within the Space Station Simulator during the 90-day confinement. Such areas as lighting, clothing, acoustic environment, and responses to the onboard habitability inventory are discussed.

An examination of crew responses indicates that the environment adequately supported the habitability needs of the four crewmen. In those instances where difficulties were apparent, recommendations are offered for design alteration in future missions.

INTRODUCTION

On an overall basis, the results of the habitability inventory (an onboard questionnaire responded to by crewmen on test days 6, 21, 35, 49, 63, 77, and 90) are presented and discussed. Following this, specific significant features are discussed. These include the onboard illumination, acoustics, clothing, and thermal control.

PROCEDURE

Throughout the 90-day test at 2-week intervals, a questionnaire was administered to the crew consisting of over 50 items which were to be responded to with a rating of subjective acceptance (questionnaire provided in Appendix A). Responses were converted to a numerical rating scale extending from 4.00 for the poorest items through 1.00 for the best. All crewmen responded to each item in the questionnaire. These responses provide the primary source of habitability data. Questionnaire responses were divided into mean responses for various significant compartments or facilities in the chamber. For example, all questionnaire items relating to the equipment quarters are contrasted with all questionnaire items relating to the waste management area. These are also related to the crew compartment and miscellaneous areas and facilities. The graph presented (fig. 1) displays the relationship among various areas and provides quantitative information on the overall habitability of the Space Station Simulator. In addition, an interesting finding results from plotting mean habitability as a function of time. Time course plotting shows the progress of adaptation of the crewmen to the environment.

RESULTS

Of all the compartments within the chamber, the crew quarters was the most acceptable. The acceptability of the crew quarters was followed by the acceptability of the equipment compartment after an initial 3-week adaptation period. While the crew quarters displayed a trend toward greater acceptability as time increased, miscellaneous features of the facility displayed a reverse trend. The hygiene area, after the first 3 weeks of adaptation, displayed no significant trend.

Those areas initially judged to be least acceptable showed a rapid adaptation to a nominal level which tended to stabilize while those areas which displayed a higher initial acceptability show a gradual improvement over a longer duration. This can be seen in the difference between the curve for crew quarters compartment acceptability and that descriptive of the hygiene area. No area, while initially acceptable, showed decreasing acceptability as a function of mission duration. The overall mean for habitability over time shows an initial acceptability rising over time and then reversing at day 90. This curve is affected to a large extent by the downward trend in the miscellaneous areas and facilities which can be more properly characterized as miscellaneous facilities rather than areas.

Crewmen's individual responses to various inventory items were averaged over the 90 days and an item comparison was accomplished permitting the development of the habitability inventory item ranks (table 1). Of 57 items indicated in the table, 55 fell within the fair through excellent range while only 2 of 57 were ranked poor. Various reasons offered by crewmen for their rankings will be provided, especially in significant areas. Floors were rated as the worst item gaining a score of 3.96 out of a possible 4.00. The reason for the floor receiving such a poor rating was not because of a structural inadequacy but because of the floor covering, which was a material spray-painted onto the surface of the cold-rolled steel substrate. The Fluorel material sprayed over a General Electric silicone primer displayed very poor adhesion throughout the mission. As time progressed, crewmen were forced to remove significant portions of the floor covering material to reduce the annoyance of the interference of floor covering material with walking. Of approximately 1,400 sq ft of material applied to the substrate before the test, about 500 sq ft remained intact on the floor. The remaining material was in very poor condition with many holes and tears through to the substrate.

Adhesion problems were probably the result of the long delay (approximately 2 months) between application of the primer and application of the Fluorel overlay. During this 2 month period, the primer became overly dry and coated with dust. Although attempts were made to clean and prepare the primer surface before application of Fluorel, they were no doubt inadequate. Where adhesion was adequate, the material displayed satisfactory resistance to surface abrasion.

Tears and holes in the flooring resulted from subsystem installation procedures undertaken prior to test initiation and were rarely initiated by onboard personnel during the test.

The Pico projector was a device supplied by the University of Chicago permitting compact storage of chromatic reading material, retrieval of this material, and display. The reason for its poor ranking resulted from a problem in the equipment design such that focusing of the display could not be accomplished. The inability to properly display the material resulted from the inadvertent insertion of a shim in the lens system. Insufficient operating instructions existed for either project personnel or on-board crewmen to remedy the situation. Had the information been available, the situation could have been corrected and the Pico projector no doubt would have received a higher ranking.

The urine collector received a low ranking simply because it malfunctioned and was not repairable. The failure occurred during the first week of the mission, after which urine collection was accomplished through the use of graduated cylinders. This was an obviously unsatisfactory system for the collection of urine, but provided individual data on urine outputs that would have otherwise been unavailable.

Throughout the section characterized as fair, may be seen numerous references to the inadequacies of the audio support equipment available to the crew either for communication with outside personnel or for recreational purposes. This is a surmountable design problem which should be given increased attention in any future missions. The cause of these inadequacies was low audio fidelity and pickup and transmission of ambient noise.

The appearance of body hygiene facilities in this section lends support to the idea that body hygiene provisions were less than adequate during the test. Particular difficulties mentioned by crewmen after and during the test were the feeling of oiliness as a residual to the use of Basic-H detergent which was the sole cleansing agent. This was reported despite the use of approximately 2 gallons of wash water per day by each man. Another difficulty with body hygiene cited by the crewmen was the dripping of excess water onto the floor area immediately in front of the onboard sink as a consequence of washcloth bathing.

The appearance of the electric oven in this section yields the impression that it was relatively less desirable than the microwave oven for food preparation. In fact, the electric oven was not used at all for food preparation. Data are available which indicate it was used no more than six times during the test and then only for the desiccation of some biological samples.

PBI thermal-knit blankets presented difficulties in use by the crew. The primary reason for these difficulties was that they tended to slide off the bunks. Since they were required for thermal comfort this was an unacceptable feature. Crewmembers sewed or pinned the blankets to Durette bedding to prevent them from sliding off the bunks during sleep. In addition, the crew recommended the use of heavier blankets for future missions under these thermal conditions.

Of all the storage volume allocations onboard the SSS, personal storage volumes were least acceptable. The reason for the lack of acceptability of personal storage volume provisions onboard the SSS is that they had been grossly underestimated and their location was inconvenient.

At the other end of the acceptance scale, storage requirements for food were satisfactory; the microwave oven was extremely well accepted as a means of reheating previously prepared freeze-dehydrated food; volumetric provisions in the equipment quarters were adequate; and light levels for the crew and equipment quarters were adequate. The latter finding reflects the ability of the crew to alter and adjust lighting conditions for 60 days of the mission and resulting perfect acceptance (ratings of 1.00).

In contrast with previous studies, the habitability inventory indicates that privacy provisions were satisfactory and crew compartment noise characteristics were acceptable. Privacy was viewed by the crew as ability to be or feel alone without interference by other crewmembers. Except in the bunk area where additional bunk isolation curtains were recommended, privacy needs were felt by crewmen to have been satisfied.

The Langley Research Center Complex Coordinator received a rating within the excellent category. This is gratifying when contrasted with findings with similar missions under similar circumstances on other devices in which crewmen discontinued performing psychomotor tasks as mission duration increased. The crew continued to perform on this device throughout the 90 days with performance showing marked improvement throughout. Subjective comments of the crew indicated they enjoyed this device, not as a means of measuring their psychomotor performance, but as a test of skill. They enjoyed competing with their own times to improve their performance. The ranking of 11 for this device versus the recreational provisions rank of 28 indicates a mismatch in recreational provisions with the needs of the crew. This is corroborated by post-test crew comments as well as observations made throughout the mission. Because of a low level of interaction and because of personal proclivities, the crew chose not to employ the games which were available to them for recreational purposes even though they had been supplied at crew request. Rather, for recreation they engaged in individualistic activities such as reading, listening to music, creative writing, and watching television.

Crew Clothing

Onboard crew clothing consisted of three types: Durette garments furnished by MDAC, polybenzimidazole (PBI) garments, and Teflon garments. The latter clothing types were supplied by NASA MSC, Crew Systems Division, for evaluation by our onboard crewmen. Material weights ranged from 3.75 oz/yd² for the Durette through 8.75 oz/yd² for Teflon. PBI materials were supplied in intermediate weights.

All clothing received consistently good acceptability responses from crewmen except the Teflon garments, which were described as too heavy, too warm, and somewhat "clammy" in our environment. Of the three clothing types crewmen preferred the weight of the Durette clothing supplied, feeling that it was consistent with the clo values required in our environment. PBI and Teflon garments were preferred over Durette garments from the viewpoint of adequacy of tailoring. The primary difference between the tailoring of the two types of garments was a fullness of the PBI garment and a close-tight-fitting configuration in the Durette garments.

Durette clothing materials initially showed what appeared to be excess surface wear and exhibited "balling" of materials on the surface. These were the result of frequent contact with abrasive surfaces. This "balling" effect proved to be of no significance in the overall wear characteristics of this material. PBI garments displayed a "balling" effect also. This was considerably less than seen with Durette. PBI materials also wore quite well.

Clothing was laundered onboard using a portable clothes washer and a small electric dryer. The detergent used for all laundering was Basic-H. At the conclusion of the mission, an inspection of the clothing revealed differences in stain retention such that Teflon and Durette displayed more retained discolorations than PBI. Apparently, Basic-H serves as an adequate stain remover for PBI, but not for Durette or Teflon.

Acoustic Environment

Criteria for the acoustic environment within the SSS were provided by NASA. They consisted of noise criteria adjusted (NCA) curve 60 for the equipment quarters and NCA 50 curve for the sleep quarters. Figure 2 presents the NCA plots for the octave bands from 45 through 11,200 Hz. Comparing the criteria with obtained values measured onboard during the 90-day test indicates that the sleep quarters, with an overall sound pressure level of 69 db, more than satisfied the requirements imposed by NCA 50. The crew quarters more than satisfied the requirements imposed by NCA 60. The equipment quarters exceeded the NCA 60 requirements on 7 of 8 octave bands. Combining the crew quarters results with those of the equipment compartment would provide a curve more closely approximating NCA 60 requirements. This was not done because the equipment quarters and the crew quarters were distinctly separate areas. The introduction of a bulkhead between those two areas to attenuate acoustic transmissions effected an approximate 6-db attenuation on the basis of overall sound pressure levels and as much as a 15-db attenuation in selected octave bands.

Adherence to these imposed criteria resulted in acceptable ambient noise levels but introduced the problem of random crew and equipment sounds, audible above background levels, as major irritants during sleep.

Lighting

A lighting experiment was conducted utilizing fluorescent fixtures and rheostat controls. During the first 30 days of the test, the crew was required to live under lighting conditions closely approximating those expected onboard Skylab A. Reactions of the crew to these conditions were solicited during this period through use of the habitability inventory. During the middle 30 days of the test, the crew was encouraged to "experiment" with various light levels and to attempt to select the most desirable levels for their tasks. During the last 30 days of the test, the crew was asked to adhere to the light level they had selected as most desirable during the middle 30 days. All procedural requirements were met including onboard weekly measurement of light values. Table 2 summarizes the findings of this evaluation. Final settings shown reflect an approximate fourfold to fivefold increase in light levels compared with Skylab values. These reflect subjective preferences, not task illumination requirements.

Thermal Environment

Characteristics of the onboard thermal environment have been presented elsewhere. In terms of crew reaction, the crew quarters was somewhat preferable to the equipment quarters throughout the mission. Habitability inventory scores showed poorest acceptance of the thermal environment on days 6, 35, and 49 with relatively better acceptability on days 21, 63, 77, and 90. Complaints on these items in the habitability inventory centered upon excess humidity, undesirably high air flows in the bunk area (which was altered by onboard crewmen), condensation of moisture on cold surfaces (especially above the bunks), and high temperatures and humidity in the equipment quarters when high work outputs were required in that compartment.

CONCLUSIONS

All available evidence suggests that the vast majority of habitability provisions were well within the range of acceptability for the crew.

Factors have been identified which may be crucial to the acceptability of a habitat. These are:

- A. Crew motivation
- B. Crew adaptability
- C. Duration of habitat utilization
- D. Initial acceptability of accommodations.

Acoustics

Crew response to noise levels indicated that the sleep area was the most acceptable from the standpoint of ambient noise. The crew quarters was next in acceptability. Least acceptable was the equipment quarters.

More irritating than background noise were noises of other crewmen and equipment. These sounds were reportedly capable of awakening sleeping crewmen. This points to the inadequacy of acoustic isolation of the bunk area despite the overall attenuation of background noise.

Clothing

Tailoring of garments toward "fullness" is more desirable than tailoring oriented toward close fit or "style".

Lighter weight materials were more acceptable for our environment than the heavier weight materials.

All tested materials display sufficient abrasion resistance to be acceptable for test durations of 90 days.

Laundrying detergents must be matched not only to water recovery systems but also to clothing materials.

Illumination

The crew definitely preferred light levels of a higher intensity than Skylab. It should be noted, however, that no onboard tasks suffered as a result of using the Skylab levels. Accordingly, it may be concluded that the Skylab light levels are adequate for crew operations if auxiliary lights are available for those tasks with high acuity requirements. Given a situation wherein electrical power limitations are not as severe as Skylab, it would be desirable, to use the higher levels.

Atmosphere Thermal Control

Greater attention must be focused upon effective temperature - a measure combining air flow, dry and wet bulb temperatures, and humidity - and workloads for the provision of a more habitable thermal environment. Attention to each of these factors on an unintegrated basis results in less than desirable but adequate thermal accommodation.

The apparent inadequacy in thermal accommodation can be accounted for to a large extent by insufficient provision for the thermal and humidity loads imposed by the solid amine CO₂ concentration system. These loads were not predicted before the test start, and were therefore not included in the thermal control design requirements. Thermal and humidity load factors for this advanced subsystem were unavailable from the manufacturer at the time of its integration into the life support system.

Appendix A

FORTNIGHTLY HABITABILITY EVALUATION

The following questions are meant to direct your attention to various factors involved in the overall habitability of the SSS. For example, there is a question concerning light levels in the general area of crew quarters, however, there are three possible sources of light in this area: (1) the fluorescent lamps, (2) the personal reading lights, and (3) the flashlight. The question does not identify specific features in the environment but is only meant to start you thinking about the area of lighting in general. For each question that evokes a non-neutral response, write the question number and your comments on the answer sheets supplied. If you truly feel that your response to the question is neutral or deserves no comment, make no marks on the answer sheet. Make sure to place your name and the test day at the top of the page.

I. CREW QUARTERS

1. Noise level

serious disturbance	moderate disturbance	slight disturbance	no disturbance
------------------------	-------------------------	-----------------------	-------------------

Comment:

2. Vibration level

serious disturbance	moderate disturbance	slight disturbance	no disturbance
------------------------	-------------------------	-----------------------	-------------------

Comment:

3. Light level

excessive	about right	inadequate	very inadequate
-----------	-------------	------------	-----------------

Comment:

4. Overall volume

*too large	about right	too small	much too small
------------	-------------	-----------	----------------

Comment:

*Any space listed as "too large", "more than enough", etc., means that this space could have been better used for some other purpose.

5. Storage volume—general

more than enough	about right	too little	much too little
---------------------	-------------	------------	-----------------

Comment:

6. Storage volume—debris

more than enough	about right	too little	much too little
---------------------	-------------	------------	-----------------

Comment:

7. Storage volume—personal

more than enough	about right	too little	much too little
---------------------	-------------	------------	-----------------

Comment:

8. Food Preparation Area

excessive	about right	inadequate	very inadequate
-----------	-------------	------------	-----------------

Comments:

9. Food Storage Area

excessive	about right	inadequate	very inadequate
-----------	-------------	------------	-----------------

Comments:

10. Recreation and Dining Table (consider aspects of size, comfort, height, area)

excessive	about right	inadequate	very inadequate
-----------	-------------	------------	-----------------

Comments:

11. Recreation and Dining Chairs (consider aspects of size, comfort, height, area)

excessive	about right	inadequate	very inadequate
-----------	-------------	------------	-----------------

Comments:

12. Bunks (consider aspects of size, comfort, height, ventilation)

excellent good fair poor

Comments:

13. Bunk Area Privacy Curtain

very useful useful annoying very annoying

Comments:

14. Privacy in General

more than
enough about right too little much too little

Comments:

15. Work/Rest Schedule

excellent good fair poor

Comments: (Identify split or common)

16. Temperature, Humidity and Air Circulation

excellent good fair poor

Comments: (Identify temperature, humidity or air circulation if problem)

II. EQUIPMENT AREA

1. Noise level

serious moderate slight no
disturbance disturbance disturbance disturbance

Comments:

2. Vibration level

serious
disturbance

moderate
disturbance

slight
disturbance

no
disturbance

Comments:

3. Light level

excessive

about right

inadequate

very inadequate

Comments:

4. Overall volume

too large

about right

too small

much too small

Comments:

5. Storage volume—general

more than
enough

about right

too little

much too little

Comments:

6. Work space

more than
enough

about right

too little

much too little

Comments:

7. Temperature, Humidity and Air Circulation

excellent

good

fair

poor

Comments: (Identify temperature, humidity or air circulation if problem)

8. Work Space Layout

excellent

good

fair

poor

Comments:

III. GENERAL HYGIENE AREA

1. Noise level

serious disturbance	moderate disturbance	slight disturbance	no disturbance
------------------------	-------------------------	-----------------------	-------------------

Comments:

2. Fecal Collection Facility

excellent	good	fair	poor
-----------	------	------	------

Comments:

3. Urine Collection Facility

excellent	good	fair	poor
-----------	------	------	------

Comments:

4. Body Hygiene Facilities: Consider water temperature, size of towels and wash cloths, adequacy of cleansing agents.

excellent	good	fair	poor
-----------	------	------	------

Comments:

5. Dryer

excellent	good	fair	poor
-----------	------	------	------

Comments:

6. Washer

excellent	good	fair	poor
-----------	------	------	------

Comments:

IV. MISCELLANEOUS AREAS AND FACILITIES

1. Internal Public Address

excellent	good	fair	poor
-----------	------	------	------

Comments:

2. Intercom to Outside

excellent	good	fair	poor
-----------	------	------	------

Comments:

3. Intercom to Internal

excellent	good	fair	poor
-----------	------	------	------

Comments:

4. Entertainment Speaker

excellent	good	fair	poor
-----------	------	------	------

Comments:

5. Entertainment Headsets

excellent	good	fair	poor
-----------	------	------	------

Comments:

6. Stepladder

excellent	good	fair	poor
-----------	------	------	------

Comments:

7. Bicycle Ergometer

excellent	good	fair	poor
-----------	------	------	------

Comments:

8. Recreational Provisions

excellent good fair poor

Comments:

9. Skylab Clothing Ensemble Warmth (Fill in garment number.)**

Jacket No. _____ Excellent Good Fair Poor

Trousers No. _____ Excellent Good Fair Poor

Shirt No. _____ Excellent Good Fair Poor

Drawers No. _____ Excellent Good Fair Poor

Socks No. _____ Excellent Good Fair Poor

Comments:

10. Skylab Clothing Ensemble Comfort (Fill in garment number) **

Jacket No. _____ Excellent Good Fair Poor

Trousers No. _____ Excellent Good Fair Poor

Shirt No. _____ Excellent Good Fair Poor

Drawers No. _____ Excellent Good Fair Poor

Socks No. _____ Excellent Good Fair Poor

Comments:

11. Skylab Clothing Ensemble Wear (Fill in garment number) **

Jacket No. _____ Excellent Good Fair Poor

Trousers No. _____ Excellent Good Fair Poor

Shirt No. _____ Excellent Good Fair Poor

Drawers No. _____ Excellent Good Fair Poor

Socks No. _____ Excellent Good Fair Poor

Comments:

**Results of these items not readily quantifiable thus they have been omitted from analyses presented in this paper.

12. Dupont 4484 bed sheet***

excellent good fair poor

Comments:

13. Durette bedding

excellent good fair poor

Comments:

14. PBI toweling***

excellent good fair poor

Comments:

15. Terry cloth towels

excellent good fair poor

Comments:

16. PBI thermal weave blankets

excellent good fair poor

Comments:

17. Durette Clothing Ensemble

excellent good fair poor

Comments:

18. Durette Pajamas

excellent good fair poor

Comments:

***Installation in SSS not accomplished. Item omitted from analysis.

19. Floor covering

excellent good fair poor

Comments:

20. Personal lights

excellent good fair poor

Comments:

21. Individual Picoprojectors ***

excellent good fair poor

Comments:

22. Group Picoprojectors

excellent good fair poor

Comments:

23. Microwave oven

excellent good fair poor

Comments:

24. Electric oven

excellent good fair poor

Comments:

25. Refrigerator

excellent good fair poor

Comments:

26. Eating utensils

excellent good fair poor

Comments:

27. Tool kit

excellent good fair poor

Comments:

28. Freezer

excellent good fair poor

Comments:

29. Body hygiene provisions (haircutting, shaving, etc.)

excellent good fair poor

Comments: (Identify as necessary):

30. Langley Complex Coordinator

excellent good fair poor

Comments:

31. RATER

excellent good fair poor

Comments:

32. Human Describing Function Experiment

excellent good fair poor

Comments:

33. Onboard laboratory work-space layout

excellent good fair poor

Comments:

34. From an aesthetic viewpoint which compartment do you prefer?**

Crew compartment

Equipment compartment

Sleep quarters

Waste Management area

Comments:

35. If you could modify the interior color scheme of the SSS how would**
you do so?

36. If you could change one color which one would it be and how would**
you change it?

37. Comments on areas and facilities not covered in questionnaire:**

38. Aside from the technical problems encountered, would you recommend**
this general configuration as a desirable living and working area for
long-term space missions? Please explain.

TABLE 1. - HABITABILITY INVENTORY ITEM RANKS
(90-DAY GROUP MEAN VALUES)

ACCEPT	ITEM	MEAN ACCEPT SCORE	RANK ORDER	ACCEPT	ITEM	MEAN ACCEPT SCORE	RANK ORDER
1.00	FOOD STORAGE	1.09	1	GOOD	HAIRCUT/SHAVE	2.16	30.5
	MICROWAVE OVEN	1.12	2		W/R SCHEDULE	2.16	30.5
	EQUIP COMPT GEN VOL	1.18	3		CREW COMPT EFF TEMP	2.20	32
	CREW COMPT LIGHT	1.21	4		BUNK LIGHTS	2.30	33
	EQUIP COMPT LIGHT	1.29	5.5		EQUIP COMPT EFF TEMP	2.39	34
	CREW COMPT PRIVACY	1.29	5.5		FECAL COLLECTOR	2.41	35
	R&D CHAIRS	1.30	7		LAB LAYOUT	2.42	36
	CREW COMPT VOLUME	1.31	8		BEDDING	2.50	37
	EQUIP COMPT S VOL	1.32	9				
	LRC-CC	1.43	11		INTERCOM/INT	2.54	38
	FREEZER	1.43	11	FAIR	FOOD PREP AREA	2.55	39
	GEN STORAGE VOL	1.43	11		RATER	2.58	40
	CREW COMPT VIBR	1.45	13		CTT	2.59	41
1.50					INTERNAL PA	2.60	42
	DRYER	1.54	14		WASHER	2.64	43
	ERGOMETER	1.57	15		BUNKS	2.66	44
	TOWELS	1.62	16		ELECTRIC OVEN	2.70	45
	DEBRIS VOLUME	1.64	17		ENT HEADSET	2.77	46
	BUNK AREA PRIVACY	1.87	18		INTERCOM/OUT	2.80	47
	EATING UTENSILS	1.89	19		EQUIP COMPT NOISE	2.89	48.5
	HYGIENE NOISE	1.93	20	POOR	BODY HYGIENE	2.89	48.5
	R&D TABLE	1.96	21.5		EQUIP COMPT WK SPACE	2.93	50
	CREW COMPT NOISE	1.96	21.5		EQUIP COMPT WK L/O	3.05	51
	REFRIGERATOR	1.98	23		PBI BLANKETS	3.09	52
	TOOLS	2.07	25		PERSONAL STOR VOL	3.11	53
	CLOTHING	2.07	25		ENT SPEAKER	3.25	54
	EQUIP COMPT VIBR	2.07	25		URINE COLLECTOR	3.32	55
	LADDER	2.08	27				
	REC PROVS	2.10	28		PICO PROJECTOR	3.77	56
	Pjs	2.14	29		FLOORS	3.96	57
				4.00			

TABLE 2.- ILLUMINATION RESULTS

MINIMUM SKYLAB LEVELS IN CP 2080

LOCATION	MEAN INTENSITY (FOOT CANDLES)
WARDROOM	5.0
WASTE MANAGEMENT COMPARTMENT	9.0
EXPERIMENT AREA	5.5

SKYLAB LEVELS AS SET IN SIMULATOR

LOCATION	MEAN INTENSITY (FOOT CANDLES)	RANGE
CREW COMPARTMENT	6.6	4 TO 9
WASTE MANAGEMENT COMPARTMENT	10.0	—
EQUIPMENT COMPARTMENT	4.0	3 TO 8

FINAL LEVELS AS SET BY CREW

LOCATION	MEAN INTENSITY (FOOT CANDLES)	RANGE
CREW COMPARTMENT	30	16 TO 36
WASTE MANAGEMENT COMPARTMENT	36	—
EQUIPMENT COMPARTMENT	17	11 TO 24

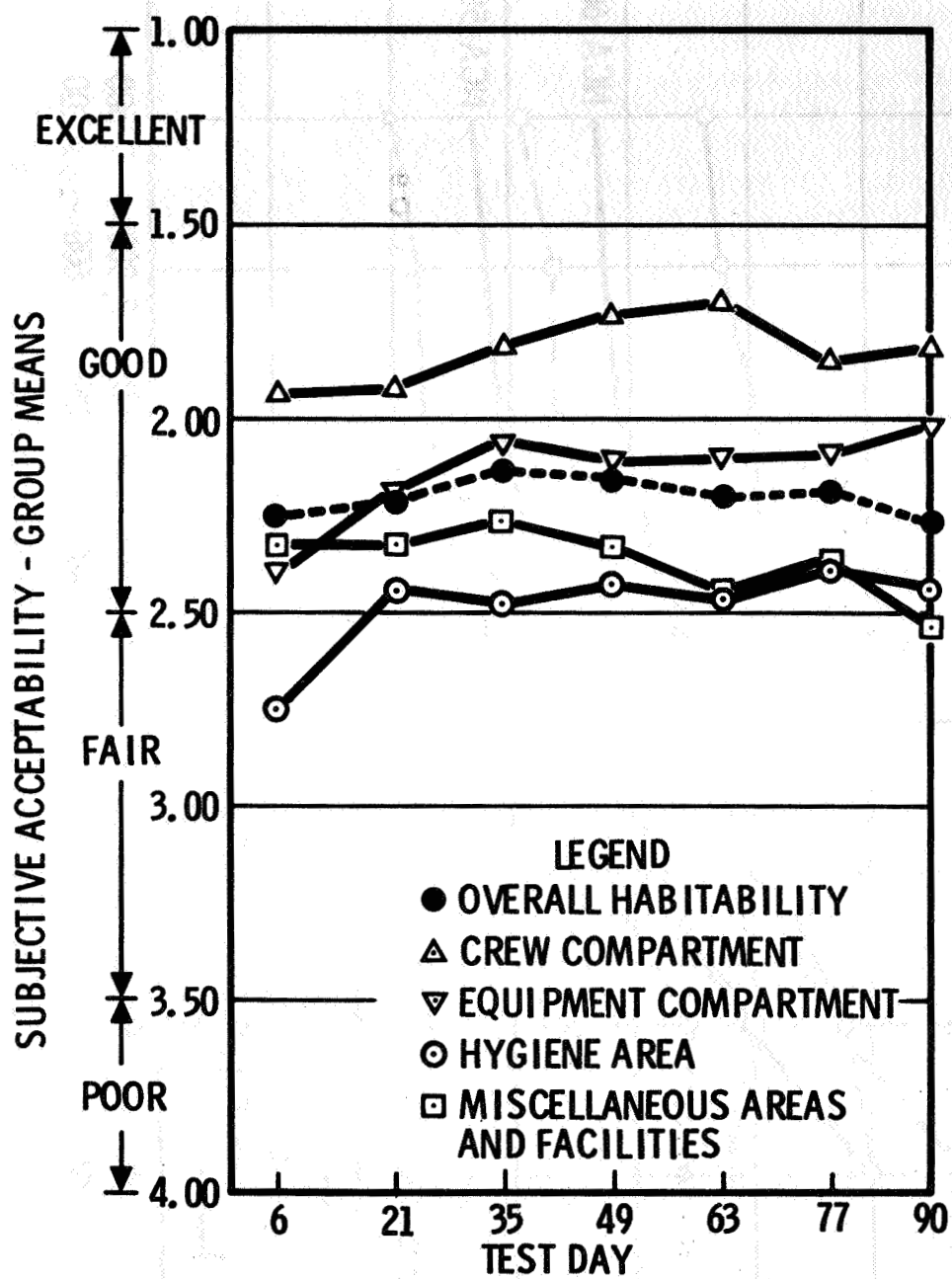


Figure 1.- Habitability inventory.

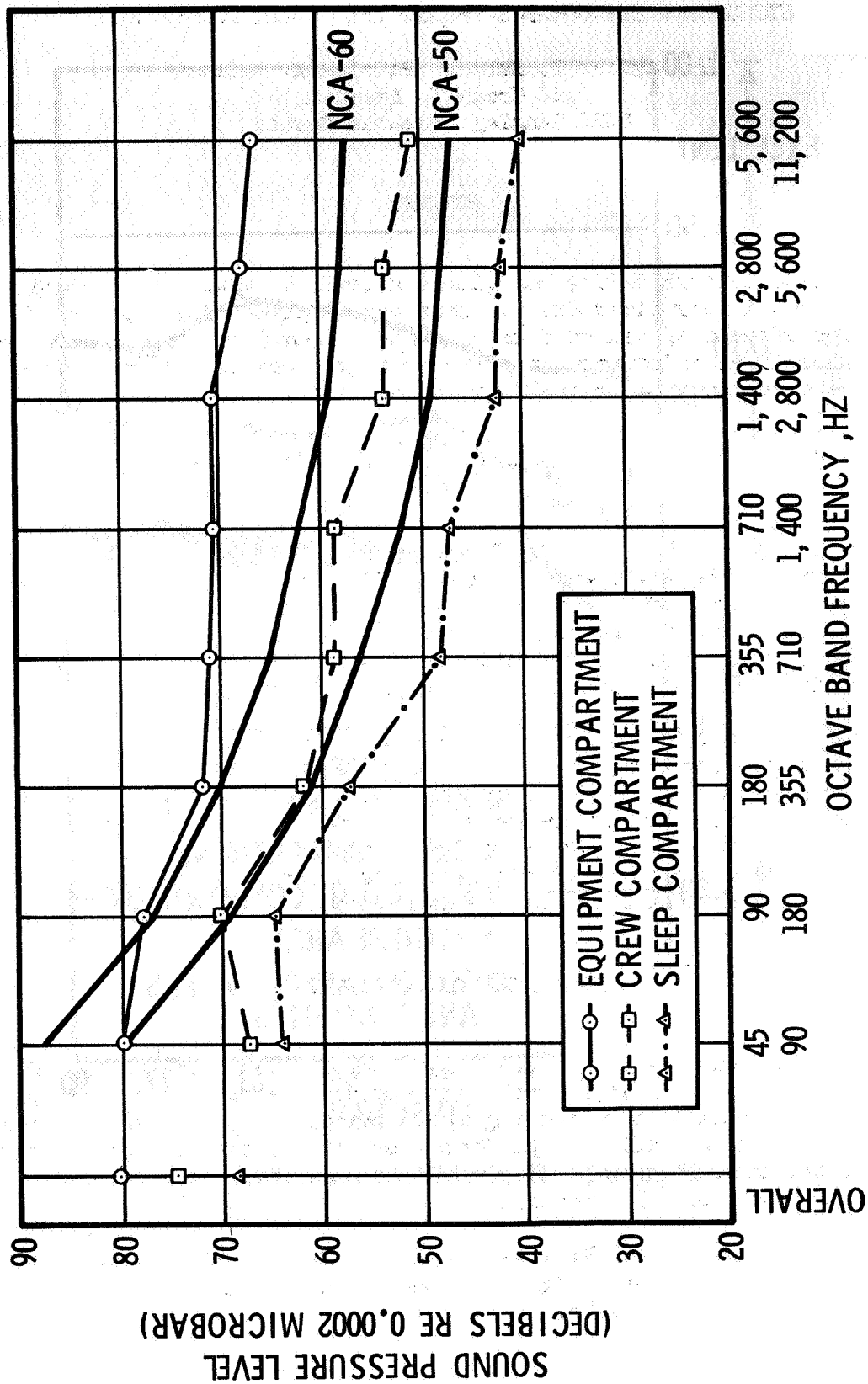


Figure 2.- Acoustic spectra and criteria.

PSYCHOMOTOR PERFORMANCE DURING THE 90-DAY MANNED TEST

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SUMMARY

A psychomotor test device was placed aboard the 90-day-test chamber. Subjects were tested four times daily. Data were analyzed for effects of confinement and for effects of selected trace gases. Long-term effects were not found; however, short-term relationships between the gas levels and the psychomotor performance were found to be small but significant.

INTRODUCTION

A psychomotor test device developed at the NASA Langley Research Center was placed aboard the 90-day-test chamber. This device, commonly called the Langley Complex Coordinator (LCC), involves a serial, self-paced task including visual discrimination and psychomotor coordination of all four limbs. Maraman (ref. 1) has given a complete description of both the test device and the performance task. This description is not repeated herein.

The major purpose of the test program was to examine the effects of long confinement on the performance of a well practiced psychomotor task. In addition, performance on this particular test device has been shown to be affected by a variety of physiological agents such as hypoxia (ref. 2) and alcohol (ref. 1). On the basis of these results it was believed that performance on the LCC might be sensitive to physiological or behavioral changes induced by the presence of agents such as gaseous contaminants.

PROCEDURE AND ANALYSIS

Each subject was trained on the LCC before the beginning of the 90-day manned test. Scores were approximately asymptotic before the test began. Later analysis has shown that there was a gradual increase in proficiency during the test. Each crewman was asked to perform a set of 100 trials four times per day. Scores were recorded as total time per 100 trials. Data were recorded for 88 consecutive days for all crewmen.

Data on average daily levels of CO, CO₂, and total hydrocarbon partial pressures were recorded, and values of other system parameters such as temperature and humidity are available.

Conventional statistical analysis could not be used because of the small number of subjects. In view of the fact that a time series of 88 data points for many variables was available, techniques adapted from stationary time series analysis were developed and appropriate statistics were derived. In particular, it was found that autocorrelation coefficients could be used to give an estimate of test-retest reliability. In addition these coefficients could be used to give an estimate of goodness of prediction over extended periods of time. Statistics for prediction based on both single test scores and optimally weighted sets of scores were derived.

In addition to the use of autocorrelation statistics, the use of cross-correlation techniques was explored. Cross-correlation techniques make it possible to analyze the effects of system parameters on individual performance. Since the cross-correlation function is asymmetric, the cross-correlation coefficients can be used together with performance scores to determine whether or not performance scores will anticipate changing levels in system parameters. Either single scores or optimally weighted sets of scores can be used with this technique also.

In addition it can be shown that either autocorrelation or cross-correlation coefficients can be used as estimates of population correlation coefficients if the individual coefficients are members of an ensemble. The standard error of estimate of the population coefficient can be estimated even though the number of subjects N is small.

RESULTS

Autocorrelation coefficients were calculated with time lags of 1 day for the first 10 days of the test. Thus, in effect, the predictability of the score on the nth day can be calculated from the score on the first day. This set of coefficients was calculated from mean daily scores. Since there were nominally four scores per day, each daily mean score is subject to considerable smoothing. The results of this analysis are presented in table I.

TABLE I.- AUTOCORRELATION COEFFICIENTS CALCULATED FROM MEAN DAILY SCORES

Lag, days	Autocorrelation coefficients for crewman -			
	1	2	3	4
0	1.0	1.0	1.0	1.0
1	.896	.929	.957	.953
2	.847	.889	.899	.907
3	.796	.859	.884	.884
4	.735	.828	.870	.861
5	.674	.798	.826	.814
6	.653	.778	.812	.791
7	.633	.748	.812	.744
8	.592	.717	.768	.698
9	.571	.687	.725	.651
10	.551	.667	.739	.651

It can be seen that the autocorrelation coefficient calculated for a time lag of 1 day is equivalent to calculating the test-retest reliability for one subject over 88 day-pairs. The set of autocorrelation coefficients calculated for all subjects for a 1-day lag is an ensemble, and each autocorrelation coefficient is an estimate of the population coefficient. In view of the relatively high values of the autocorrelation coefficients, no estimate of the population coefficient was deemed necessary.

Since smoothing must affect the autocorrelation function and will of necessity obscure short time variance, the same analysis was carried out for a time lag of 1 test period. These data are presented in table II.

TABLE II.- AUTOCORRELATION COEFFICIENTS CALCULATED FROM TEST SCORES

Lag, tests	Autocorrelation coefficients for crewman -			
	1	2	3	4
0	1.0	1.0	1.0	1.0
1	.692	.853	.714	.815
2	.808	.794	.633	.815
3	.611	.795	.612	.778
4	.692	.809	.653	.741
5	.635	.750	.592	.741
6	.654	.750	.551	.741
7	.635	.794	.510	.741
8	.712	.750	.469	.704
9	.539	.706	.612	.704
10	.673	.721	.633	.704

It is obvious that the portion of the LCC score variance accounted for by test-retest correlation is somewhat less when the autocorrelation coefficient is computed for a time lag of 1 test period. These results indicate short time variance which may be presumed to be due to both random effects and some systematic effects from other variables.

Cross-correlation coefficients were calculated for the relationship between LCC scores and both CO and CO₂. The correlations between the mean LCC scores and mean partial pressures for CO and CO₂ are presented in table III.

TABLE III.- CROSS CORRELATION BETWEEN LCC SCORES AND GAS PARTIAL PRESSURES

Gas	Cross-correlation coefficients for crewman -			
	1	2	3	4
CO ₂	-0.138	-0.210	-0.126	-0.200
CO	.145	.197	.251	.1414

There is evidence of a small but significant correlation for both gases. The coefficients as presented are significant at a level of approximately 0.03. However, it was found that there is some covariance in the data. The CO and CO₂ pressures were found to have a correlation of 0.300, which is significant beyond the 0.01 level.

If ensemble averaging is applied, it is found that the estimated population correlation coefficient for the relationship between the ICC scores and the CO₂ partial pressure is approximately -0.250 when partial correlation adjustment is made for the CO-CO₂ covariance. The estimated population correlation coefficient for the relationship between the ICC scores and the CO partial pressure is 0.252 when this adjustment is made. Since both these coefficients have over 300 degrees of freedom, both are significant at levels approaching 0.001.

DISCUSSION

The data presented in table I are essentially estimates of the predictability of mean or smoother scores and hence are estimates of the long-time stability of the psychomotor skill. It is believed that there is evidence to support the conclusion that over a long time period the ICC score is highly predictable and hence quite stable. In fact, there is evidence that learning continued to take place for the duration of the test. This learning was of such a degree that removal of most of the effects of learning by fitting a straight line as a first-order approximation of the learning curve was necessary to avoid the possibility of spurious correlations.

The data presented in table III are based on adjusted ICC scores and the gas partial pressures. These correlations, while small, are believed to be valid. Both the absolute partial pressures and the variations in pressure were relatively small and thought to be below the level of significant physiological reactivity. It is thought that the results of this preliminary analysis are suggestive of the need for further research directed towards the use of behavioral methods as indices of trace gases.

These inferences are further supported by the fact that for both gases the relationship suggested by the correlation coefficients is consistent with known physiological data. At low levels CO₂ is known to be a stimulant, while it may be suspected that at some levels CO will have a negative effect on performance.

CONCLUDING REMARKS

A psychomotor test device was placed aboard the 90-day-test chamber. Subjects were tested four times daily. Data were analyzed for effects of confinement and for effects of selected trace gases. Long-term effects were not found; however, short-term relationships between the gas levels and the psychomotor performance were found to be small but significant. The analysis presented

herein is only a small portion of that planned for the data gathered during the 90-day manned test.

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CREW PERFORMANCE ON SIMULATED CONTROL TASKS

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SUMMARY

In order to test various components of a regenerative life support system and to obtain data on the physiological and psychological effects of long-duration exposure to confinement in a space station atmosphere, four carefully screened young men were sealed in the McDonnell Douglas Astronautics Space Station Simulator for 90 days with no pass-in's allowed. Under contract to the NASA Ames Research Center,* Systems Technology, Inc., administered a tracking test battery during the above experiment. The battery included a "clinical" test (Critical Instability Task) related to the subject's dynamic time delay and a conventional steady tracking task during which dynamic response (describing functions) and performance measures were obtained. The subjects were extensively trained prior to confinement and generally reached asymptotic performance levels.

Good correlation was noted between the clinical critical instability scores and more detailed tracking parameters such as dynamic time delay and gain-crossover frequency. The levels of each parameter spans the range observed with professional pilots and astronaut candidates tested previously. The chamber environment caused no significant decrement on the average crewman's dynamic response behavior, and the subjects continued to improve slightly in their tracking skills during the 90-day confinement period. Some individual performance variations appeared to coincide with morale assessments made by other investigators. The comprehensive data base on human operator tracking behavior obtained in this study should be further correlated with concurrent psychological, physiological, and environmental data obtained by others during the 90-day confinement study.

*This research was sponsored by the Man-Machine Integration Branch of the NASA Ames Research Center under Contract NAS2-4405 (Modification-5). The tasks and associated hardware used in this study were previously developed under the same contract. M. Sadoff and N. McFadden have been the Ames Project Technical Monitors throughout the program.

INTRODUCTION

A 90-day sealed chamber test of a regenerative life support system was performed at the McDonnell Douglas Astronautics Corporation (MDAC) under NASA Contract NAS1-8997 from the Langley Research Center. Among the stated objectives of the official test plan and procedures (Ref. 1) are the following:

"...5. To demonstrate man's capability...for in-flight monitoring of necessary human...parameters.

6. To obtain...data that will assist in determining the precise role of man in performing in-flight experiments... and...in validating mathematical models of [manned] space missions.

7. To obtain data on physiological and psychological effects of long-duration exposure to confinement in the cabin atmosphere...."

To accomplish these objectives, four men, carefully screened for compatibility with each other and with a confined environment, were sealed in the MDAC Space Station Simulator (SSS) for three months with no pass-in's allowed; also, only a limited number of pass-outs allowed for medical sampling purposes. The primary workload of the subjects included monitoring and maintenance of SSS life support equipment and monitoring and recording their metabolic, medical, and mood characteristics. The SSS environment was "closed-cycle" and included a subnormal air pressure of $3/4$ atmospheres with normal oxygen partial pressure.

This program also provided a unique opportunity to evaluate certain other psychomotor and cybernetic functions in a realistic space station environment (except for zero-gravity) and under operational type work-rest cycles and ambient stresses. Among the more important of such psychomotor tasks are the broad class of tracking tasks: star tracking for navigation or astronomical purposes; telescope pointing for earth resource or reconnaissance purposes; fine tuning of apparatus for research or communications purposes; and, last but not least, piloting tasks such as rendezvous in orbit and reentry into the earth's atmosphere. (At least one of the crew members is likely to be a pilot or trained as a pilot for such emergencies.)

In order to measure behavior appropriate to such tracking tasks, Systems Technology, Inc., under sponsorship by the NASA Ames Research Center's Man-Machine Integration Branch, provided a battery of tracking tasks to be performed during the 90-day mission. The objectives of this experiment were:

1. To obtain a simple "clinical" measure of the crewmember's visual-motor dynamic performance on a routine basis using the so-called "Critical Instability Task" (Ref. 2).
2. To obtain comprehensive measures of the intrinsic dynamic response properties on a less frequent basis by means of advanced cross-correlation techniques and to correlate

this standard tracking-task data with the critical instability measure.

3. To present data obtained in this tracking experiment for correlation with medical physiological and psychological data from other experiments run concurrently.

The tracking task test battery and associated apparatus employed in this experiment were developed under NASA sponsorship and are detailed in Refs. 2-6. Systems Technology's role in the present experiment was to provide test specifications and experimental design and procedures; to participate in indoctrination and training; and to reduce and analyze the data. Douglas personnel were responsible for integrating the equipment and tests into the 90-day Experiment and for administering the control task test sessions.

CONTROL TASKS AND EXPERIMENTAL SETUP

Control Tasks

The psychomotor tests used in this experiment are continuous, compensatory visual-motor tracking tasks. A general block diagram representation of these tasks and associated data measures and analysis is shown in Fig. 1. A thorough description of these tasks is given in Refs. 5 and 6. Basically, the subject is required to control the motion of a luminous horizontal CRT line with an isometric (force) control stick whose output controls a dynamically unstable controlled element [first-order: $Y_{c1} = \lambda_1 / (s - \lambda_1)$; second-order: $Y_{c2} = \lambda_2 / s(s - \lambda_2)$]. If the subject provides the appropriate dynamic equalization behavior he will be able to not only stabilize the man-machine system, but to minimize CRT line motions away from the null point or reference line. Two variations of this unstable tracking task employed in the present experiment are described below:

1. Critical Instability Task

The subject is required to maintain stable control as the controlled element's instability is steadily increased. No external disturbance need be introduced in this task because "remnant" noise sources internal to the human operator (e.g., unsteadiness, tremor) provide ample excitation for the unstable element. In the face of the increasing instability the subject will lose control of the task at some point because the line diverges off the CRT more quickly than he can exert compensatory control action. The degree of instability, λ_c , at which the subject loses control is termed his "critical instability" score. It is roughly equal to the inverse of the operator's dynamic time delay as shown in Refs. 2 and 3.

The control of simple first-order divergent dynamics is called the first-order critical task and requires the operator to act as a simple gain (i.e., the operator's stick output looks like a scaled version of

the system error signal including a time shift equal to the operator's dynamic time delay). Controlling a first-order divergence in series with a pure integrator is called the second-order critical task. In controlling these dynamics the operator must effectively cancel out the effect of the integrator by providing what we term first-order lead equalization in order to stabilize the control dynamics. (Lead equalization is equivalent to rate perception or error signal prediction.) Generation of this lead equalization requires additional mental processing time (Ref. 7) which increases the operator's effective dynamic time delay. Thus for the second-order critical task the operator can't achieve as high a critical instability score as with the first-order task.

The operator's basic effective time delay, as measured by the first-order critical task, is composed primarily of neural conduction time delays and neuromuscular dynamics of the arm. Thus performance on the first-order critical task is a measure of basic neuromuscular dynamics, while the second-order task measure includes a component due to higher center involvement.

The critical task is easily administered since it only requires about one minute per trial and a single number is recorded at the end of each trial. Therefore, the first- and second-order critical instability tasks were selected to be administered routinely during the 90-day confinement test.

2. Steady "Subcritical" Tracking Tasks

For steady tracking tasks the instability level of the unstable dynamics is held constant at a value well below the typical subject's critical instability score. An unpredictable command input is introduced into the tracking loop as shown in Fig. 1, and the subject is asked to maintain minimum tracking error during runs lasting approximately 2 min. Using special apparatus to be described later, the error signal is Fourier analyzed and performance data are computed during the run. These data are further reduced off-line, via a time-sharing computer program, to obtain the subject's open-loop describing function and task performance. The describing functions are fitted with a three-parameter dynamic response model, and the resulting loop closure properties are interpolated. Key parameters presented herein include:

Crossover frequency (ω_c), the unity-amplitude frequency of the open loop describing function, a measure of the subject's gain.

Phase margin (ϕ_m), a measure of system stability margin related to the closed-loop damping ratio.

Dynamic time delay (τ_e), the subject's visual-motor time delay in a continuous tracking task including neural and mental delays and neuromuscular lags.

The performance measures include:

Normalized error variance (σ_e^2/σ_i^2), the ratio of tracking error variance to the variance of the task input.

Error coherence (ρ_e^2), the percentage of total variance predicated by (correlated with) the describing function measurements. The remaining error power ($1-\rho_e^2$) is due to the subject's internal noise (remnant).

For this experiment we chose to include both first- and second-order subcritical tracking tasks that are dynamically equivalent to the first- and second-order critical instability tasks. The first-order instability was set at $\lambda_1 = 2$ rad/sec, and the second-order case was set at $\lambda_2 = 1.25$ rad/sec. Although these tasks allow a detailed assessment of the subject's dynamic response and noise properties, they require longer trial durations and a large amount of on-line data collection and reduction. For this reason they were run less frequently than critical tasks during the 90-day test, and were employed to provide realistic tracking task data to correlate with the critical instability scores.

Test Setup and Equipment

The experimental layout and apparatus are shown in Fig. 2. The test administrators conducted the experiment from the control room where the task computers were located. The Controlled Element Computer (CEC) provided the unstable dynamics for the tracking tasks, and automatically increased the instability during critical task runs as shown in Fig. 1. The Describing Function Analyzer (DFA) provided the subcritical tracking task input, Fourier analyzed the tracking error signal, and measured various performance parameters.

The display and control stick, connected to the computers through a 100-ft cable, were located in the space chamber recreation area. The Douglas Test Administrator communicated with the crewmen through an intercom, and also via interconnected "ready" lights located on the subject's display and the controlled element computer.

TRAINING

Crewmen began training on the first- and second-order critical tasks four months prior to commencing the 90-day confinement period. This training consisted of approximately 30 one-hour sessions spanning a five-week period. At each session the crewmen would track 2 three-trial blocks of the first-order critical task and 2 five-trial blocks of the second-order critical task. These λ_{c1} and λ_{c2} training scores are plotted in Fig. 3(a). It is evident that all crewmen reached stable levels of critical instability within about 100 trials of distributed practice.

Training of the steady tracking tasks was commenced immediately after critical task training. Because of the dynamic similarity between the critical and subcritical tasks, a favorable transfer of training is assured. The crewmen tracked three first-order and three second-order runs per session for approximately ten sessions spanning a four-week period. Dynamic response data for the first- and second-order tasks is plotted in Figs. 3(b) and 3(c). From Figs. 3(b) and 3(c) the crossover gain, ω_c , shows a gradual increase with training, while the stability margin, ϕ_m , shows a concurrent decrease. Stable training levels were achieved in all cases except for Crewman 4 on the second-order task. He had significantly less exposure to this task than the other crew members, and he later exhibited correspondingly larger learning effects during the confinement period.

90-DAY CONFINEMENT TESTS

General

During the confinement period, three trials of first-order and five trials of second-order critical instability task were administered routinely every Monday, Wednesday, and Friday, following the midday meal. These data formed the core of our experimental design, and represent a base from which other tracking data can be compared and extrapolated. Steady tracking sessions were performed twice a week, one session for each order. These sessions began with the critical instability trials of the equivalent dynamics in order to provide a warmup and also to provide concurrent correlations between λ_c and the more comprehensive measures of steady tracking behavior.

The crewmen were split into two shifts, with Crewmen 1 and 2 on a nominal day shift (0700-2300 Hr) and Crewmen 3 and 4 on a graveyard shift (2100-1300 Hr). Illumination was held constant inside the simulation chamber, and all indications are that Crewmembers 3 and 4 quickly adjusted to their abnormal work shift. Test sessions were conducted after the midshift meal (nominally 1300 Hr for Crewmen 1 and 2, and 0200 Hr for Crewmen 3 and 4). All test sessions began with a warmup critical instability trial.

Critical Instability Results

Weekly mean critical task scores (averaged across the solely λ_c sessions for each week) are plotted in Fig. 4. Generally, these scores were very reliable (low residual variance) and showed a consistent stratification among crewmen. Crewman 1 evinced the most variable performance, with a definite dip in scores during the initial confinement period compared with his preconfinement baseline. This dip was followed by a return to performance levels significantly above his preconfinement baseline. There is one very consistent dip in performance for all crewmembers during Week 9. In a discussion with M. V. McLean of McDonnell Douglas it was determined that a definite dip in morale occurred in this period.

There is a consistent, albeit small, improvement trend apparent over the 90-day period in all cases except for Crewman 3 on the second-order task. Experience suggests that this reflects a residual improvement in the neuromuscular system due to continuous practice beyond the initial training asymptote—much as in any athletic skill involving strength.

Analysis of variance procedures applied to the data showed subjects and weeks to be significant main effects. The subjects by weeks interaction was also statistically significant.

Steady Tracking Results

The steady tracking behavior and performance data are plotted in Fig. 5. (The critical instability data shown here were obtained at the beginning of each subcritical tracking session, and were not included in Fig. 4.) The steady tracking data are often missing because these sessions had a somewhat lower priority than the critical task sessions and were not performed for a variety of reasons.

The dynamic response data (ω_c and ϕ_m) and critical task scores (λ_c) seem to remain fairly consistent and similar in level over the 90-day period. The normalized error and error coherence performance measures (σ_e^2/σ_1^2 and ρ_e^2) show considerable variations, however. Crewman 4's tracking errors are significantly higher than that of the other crew members. This result seems to be due primarily to an intrinsically higher remnant level as evidenced by his lower error coherence scores for both the first- and second-order tasks.

Crewmen 1 and 4 were still learning the second-order steady tracking task during the first half of the confinement period, as reflected in their normalized error scores. This result seems to be primarily due to dynamic response effects as both subjects show a corresponding increasing trend in crossover gain during the first half of the mission.

The comprehensive variety of measurements made during steady subcritical tracking will help in interpreting variations in tracking behavior and performance. A good understanding of the theoretical relationships among the above parameters exists (e.g., Ref. 6), and this will be used to unravel the seemingly complex and anomalous variations exhibited in Fig. 5.

Correlation Between Subcritical and Critical Task Results

One of the objectives of this experiment was to tie in the dynamic response measurements obtained during steady tracking tasks with the critical instability scores. Some correlation of critical and subcritical task data is shown in Fig. 6. Effective dynamic time delays (τ_e) were derived from the dynamic response measurements obtained during subcritical tracking runs, and the inverse of τ_e should be directly related to critical task scores as discussed in Refs. 2 and 3. The good correlation of τ_e^{-1} versus λ_c scores obtained during each

subcritical tracking session ($R = 0.74$) is shown at the top of Fig. 5 for both first- and second-order tasks. Because it is ultimately bounded by τ_e^{-1} and hence by λ_c , crossover frequency (ω_c) has also been shown to correlate with λ_c (Refs. 5 and 6). The good correlation in this experiment ($R = 0.64$) is shown at the bottom of Fig. 5. The present correlations, with initially naive subjects, are somewhat less than similar ones made in Refs. 5 and 6 among professional pilots, but the trends and fitted lines are similar. The good tie-in of the present tracking behavior, performance, and critical instabilities with previous data constitute a strong validation for the generality of the models and interrelationships observed. Further analysis is now in order to compute the empirical factors via the theoretical models and the present data.

The absence of profound decrements in the performance data, tracking behavior, or critical instability scores should come as no surprise since the chamber environment was maintained in a generally satisfactory state.

CONCLUDING REMARKS

Crewmen performance in this experiment agrees quite favorably with that of experienced pilots and test subjects tested previously. No serious degradations in performance were noted during the mission, and in fact there appeared to be a slight improvement trend throughout the 90-day period. Some dips in individual performance seem to correlate with subjective attitude and morale data not shown, so correlations of tracking data with other psychological measurements as well as with physiological and environmental data should be pursued.

A rich harvest of statistical data on manual control behavior has been obtained in this experiment. Its further analysis should tell us a great deal about the consistency and measurability of human dynamic response properties over an extended period of time under confined conditions.

The control task equipment functioned properly throughout the mission, even though the CRT display and control stick were subjected to the simulator sub-atmospheric pressure. In spite of the apparent complexity of the equipment and test protocols, both the crewmen and test administrators quickly became proficient in the experiment procedures. Test sessions for one subject typically required less than 15 min. Thus the simpler equipment and tests being planned for future orbital use by astronauts should meet with good acceptance and allow us to obtain in-depth information regarding the space environment's effect on human dynamic response properties.

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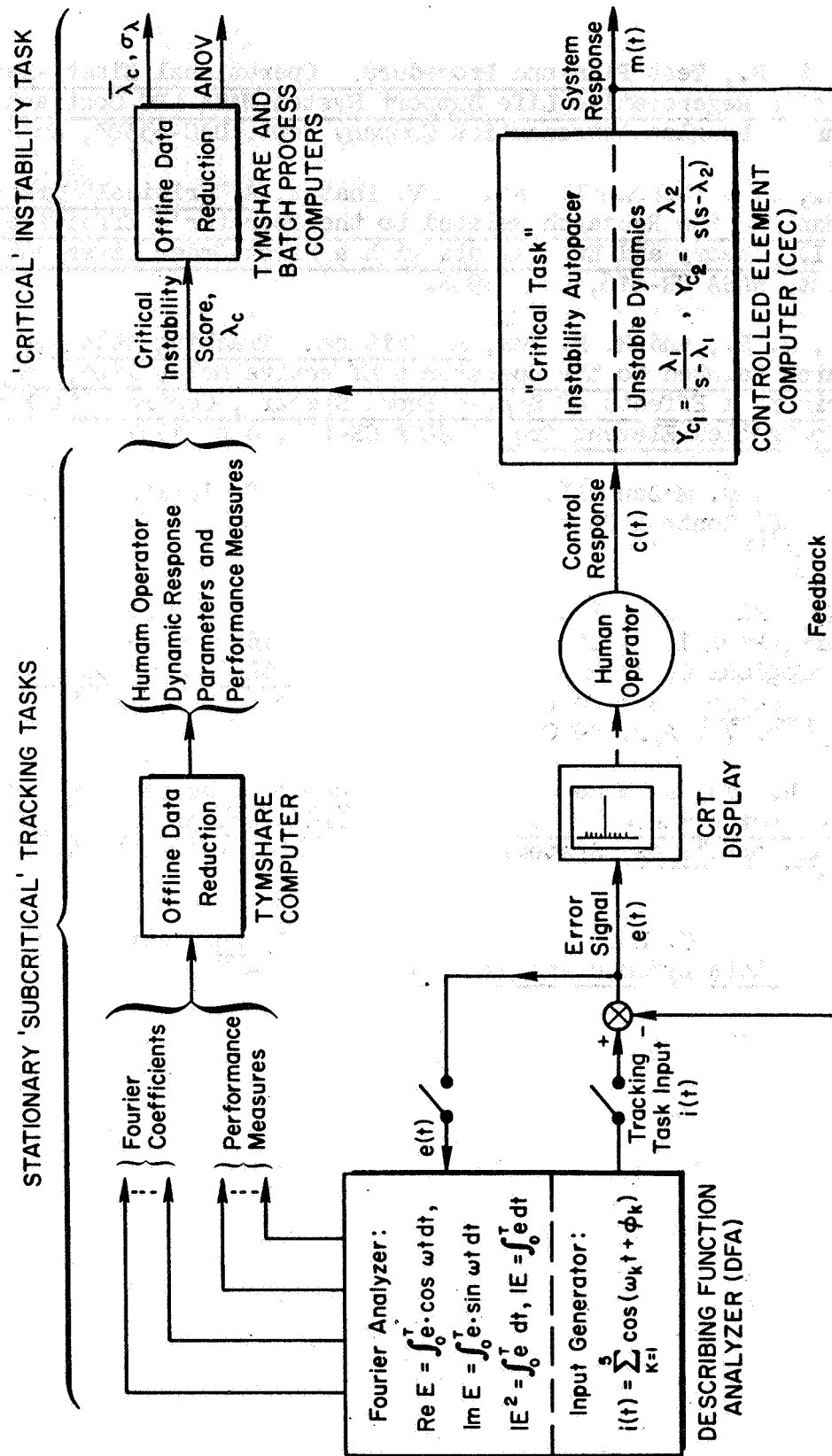


Figure 1.- Tracking tasks, data measurements, and analysis.

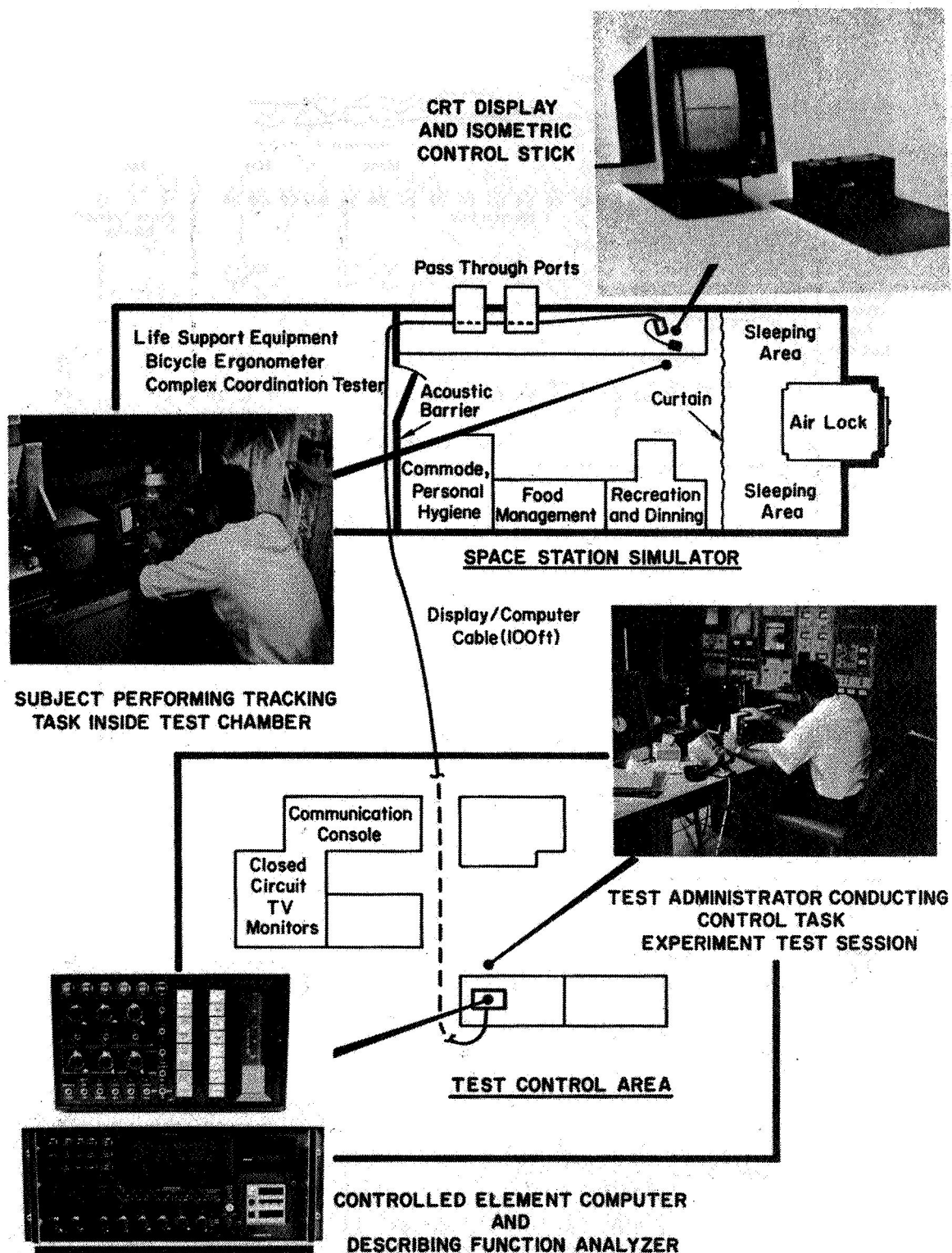


Figure 2.- Control task apparatus and experimental setup for the 90-day confinement study.

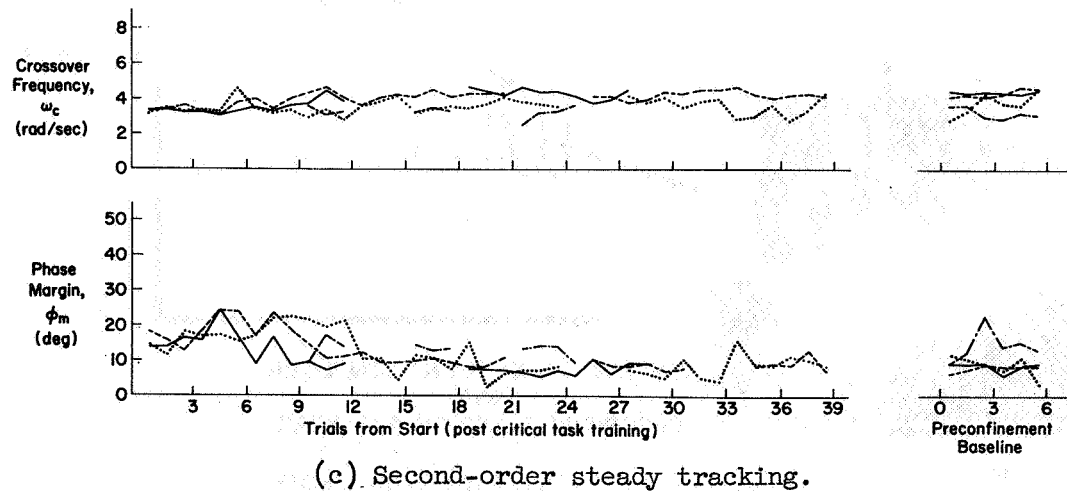
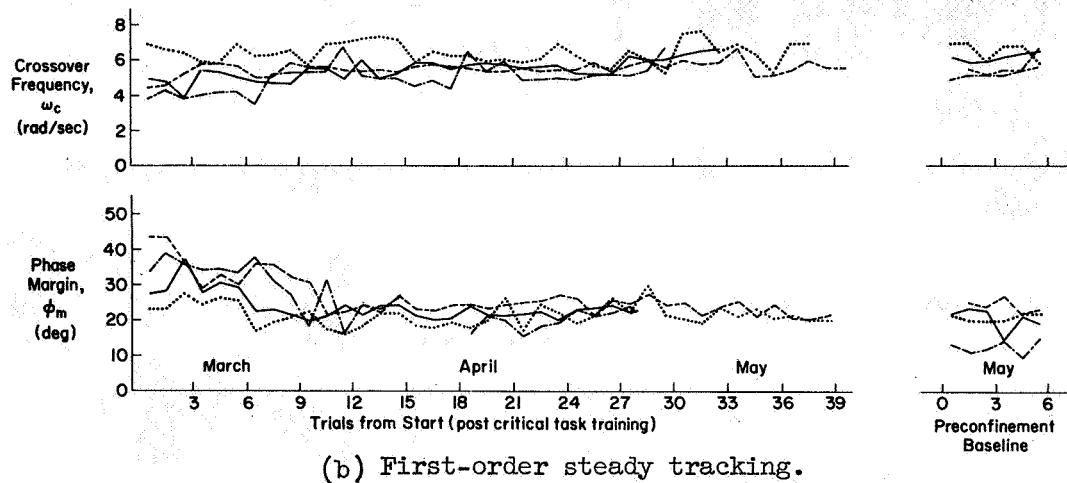
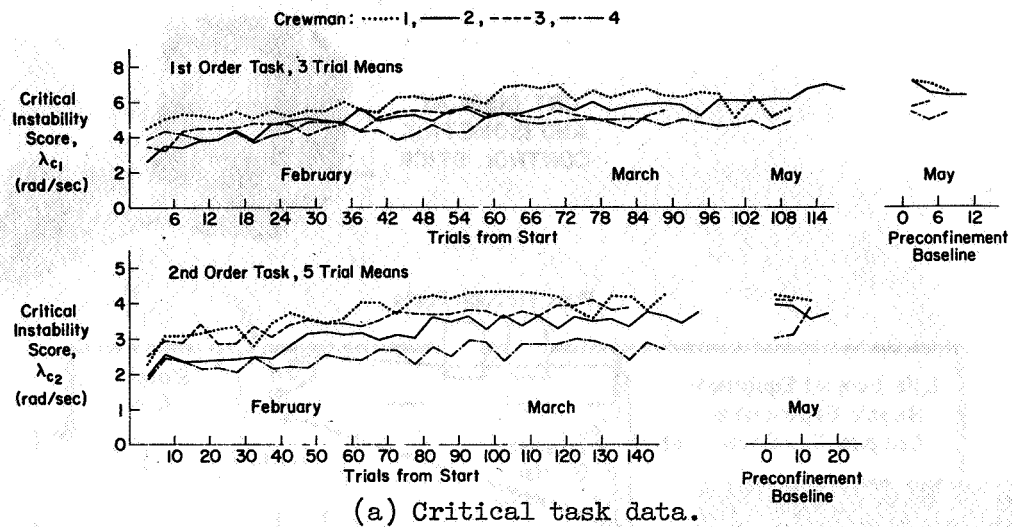


Figure 3.- Training data.

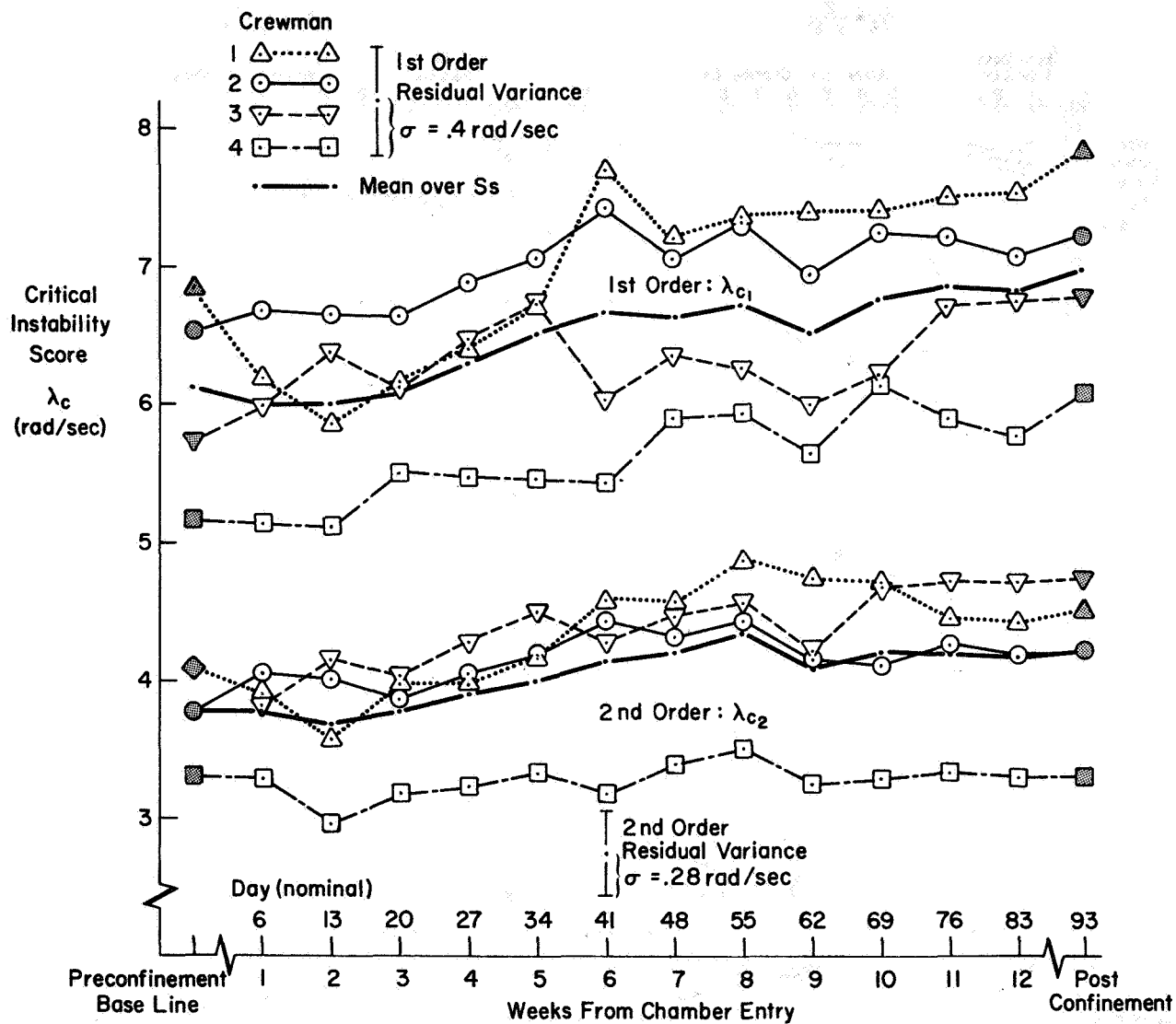


Figure 4.- Weekly mean critical instability scores during the 90-day confinement period.

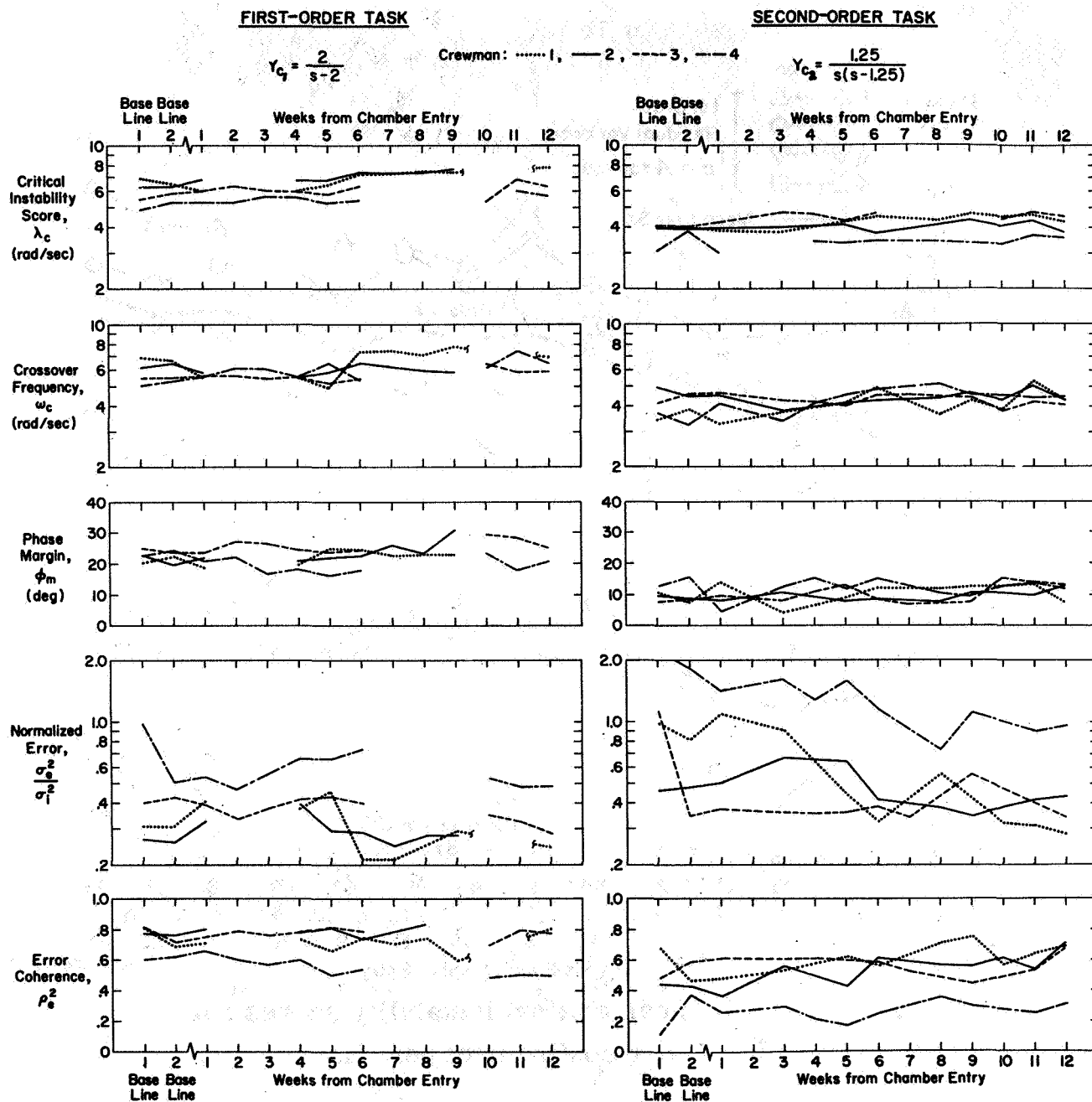


Figure 5.- Comparison of tracking-session data
for the 90-day test.

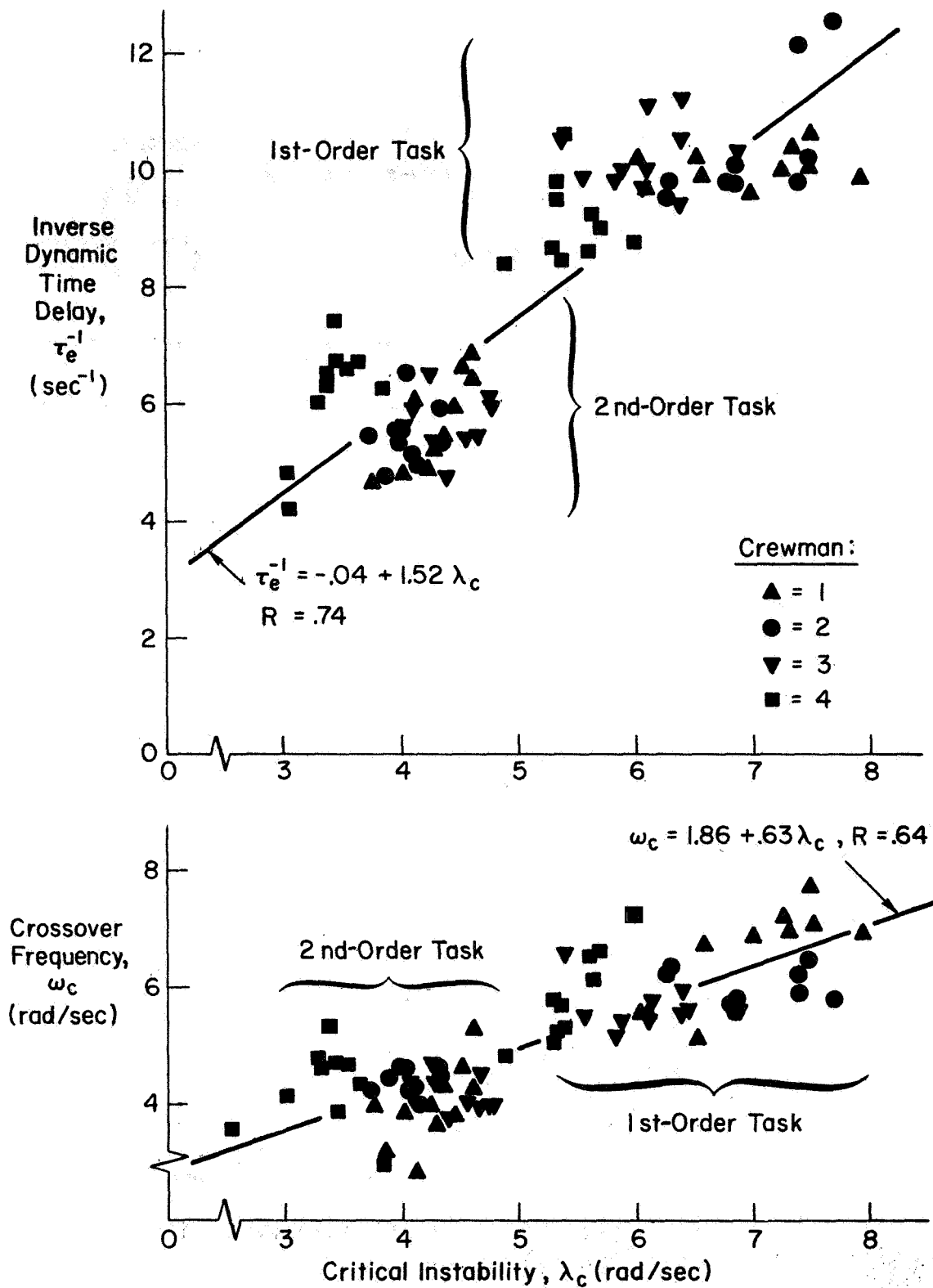


Figure 6.- Correlation between critical instability score and steady tracking data.

EFFECTS OF LONG DURATION CONFINEMENT ON SHORT-TERM MEMORY

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A short-term memory test device, the Response Analysis Tester (RATER) developed by General Dynamics, San Diego, was used in the 90-day study. Prior to the selection of RATER, an extensive literature survey and an evaluation of available performance tests were made. The goal of this effort was to locate tests of higher order functioning which could be used to measure performance in a wide variety of stress situations. Results of the survey indicated that RATER showed promise of providing a stable sensitive test of one aspect of higher order functioning.

RATER is shown in figure 1. The larger unit contains all the controls and indicators needed for administration of the test and collection of the data. This unit remained outside the test chamber. Only the small display and response unit was inside. The subject sat in front of this unit and viewed the screen of a one-plane readout. A series of symbols appeared in a random sequence on the screen. Four different symbols were used: triangle, circle, plus sign, and diamond. Four response buttons were located on the response unit, and each was associated with one of the four symbols. The subject's task was to press the appropriate response button each time a symbol appeared.

Two test conditions, delay and no delay, were used. The no-delay condition required that the subject respond to the symbol currently being presented, and no short-term memory was involved. The delay condition required the subject to respond according to the symbol that had been presented two stimulus events prior in the sequence. Since all responses had to be delayed by two symbols, short-term memory was required throughout this test condition. The experimental hypothesis was that short-term memory would be impaired by the stress of confinement. Thus, performance impairment was predicted for the delay condition, but not for the no-delay condition.

Since only a small amount of RATER test data had previously been published (refs. 1 to 3), additional data were needed. To meet this need, a large group of male college students was tested in the Human Performance Laboratory at Ames Research Center. The results of this test program were used in the selection of a set of test conditions for the 90-day study.

Since most of the Ames laboratory subjects continued to show performance improvement over a large number of test sessions, and since asymptotic performance was desirable prior to confinement, 28 training sessions were specified for the 90-day study. A stimulus presentation rate of one symbol per second was selected. A two-symbol delay seemed to provide the desired level of difficulty for the short-term memory testing. Results of the laboratory study were also used to determine the minimum amount of data needed from each test session so that the sessions could be as brief as possible, but still provide adequate data.

For the 90-day study, each test session consisted of a 1-minute warm-up test, a 30-second rest period, and then four 3-minute test periods with a 30-second rest period between tests - a total of 15 minutes. The two test conditions, no delay (I) and two-symbol delay (II), were alternated over the four 3-minute test periods in two ways: I-II-I-II (schedule A) and II-I-II-I (schedule B). For each subject, the two schedules were alternated over test sessions. The test condition (I or II) for the 1-minute warmup was the same as the first 3-minute test for any given session.

Since the subjects could make more than one response to each RATER symbol presentation, performance was scored by subtracting the number of errors from the number of correct responses. Both of these values were read directly from counters on the control unit, and were recorded during the 30-second rest following each test period. Immediately after recording each score, the experimenter verbally reported the score to the subject. For each session, the 6 minutes of testing on each condition at a symbol presentation rate of 60 per minute allowed a maximum possible score of 360. Warmup scores were not included in the data.

The test results are shown in figure 2. The set of curves at the left shows the results for the training sessions prior to the beginning of confinement. The number of training sessions completed varied among the four subjects as follows: 15, 19, 22, and 28. Only the first 15 sessions are presented because performance of the three subjects who completed additional training neither improved nor declined after the fifteenth session.

Performance was very stable in the early days of confinement; a marked improvement in the two-delay condition occurred between days 12,13 and 18,19.* By the 18th and 19th days of confinement, the subjects had achieved almost perfect performance for both test conditions. At this time, the subjects seemed to be losing interest in the test; thus a decision was made to increase the task difficulty, and thereby the challenge, by increasing the symbol presentation rate. With this increase in the number of stimulus presentations, the maximum possible score rose from 360 to 480. After the rate change, the group mean for the two-delay condition began to decline, reached a very low level on the 28th and 29th days, and then rapidly recovered. Unfortunately, during the same time period some test sessions were canceled for reasons unrelated to the RATER study, and other data were lost because of RATER malfunction. Thus, the group means for several sessions represent data for fewer than four subjects. For these sessions the number of subjects represented is shown directly below the session numbers in figure 2. (For example, 2Sg means 2 subjects; 2Sg2D means 2 subjects and 2 delays; 1SND means 1 subject, no delay.) On the 33rd day of confinement, the test equipment failed. Despite efforts to have it repaired as quickly as possible, it was not restored to satisfactory operation until the 68th day. At this time, partly because the subjects had requested that the test be given less often and partly because additional apparatus failure would mean another long repair delay, a decision was made to test only every fourth day rather than every other day. When testing was resumed, the group

*On days 4 to 33 only two subjects were tested each day; thus, the group means represent data combined from two consecutive days.

mean for the two-delay condition began at a rather low level but rose to reflect rather good performance toward the end of the study.

The performance decrements that have been discussed are not representative of the individual performance of all subjects. One subject had very substantial decrements which strongly influenced the shape of the group curve for the two-delay condition. Figure 3 shows the test results, the data for that subject being removed. After the rate change, there is no large decline in performance for the three subjects. However, it is obvious that the test had become more difficult and the subjects' performance never became as consistent or as close to the maximum possible score as it had been with the slower presentation rate. The decrements on day 75 are due, at least in part, to the fact that the values represent data for only one subject. Because of an oversight, the other two subjects were not tested at all on that day.

While the 90-day confinement study was in progress at McDonnell Douglas, the authors of this report participated in a 14-day confinement study at the University of Pennsylvania. For this study, six men were confined in a test chamber containing nitrogen enriched air (95% N_2) at a pressure of 4 atmospheres. The study was conducted in support of the TEKTIME II Program, specifically in support of a proposed series of saturation dives at an undersea depth of 100 ft. The pressure and gas composition of the Philadelphia chamber environment duplicated the expected conditions of the TEKTIME program.

Compared with the 90-day study, the Philadelphia study involved a much more acute stress that had a specific physiological basis. This physiological stress was nitrogen narcosis, frequently experienced by divers, which produces symptoms similar to those of alcoholic inebriation. Figure 4 shows the Philadelphia data (group means) plotted in a manner directly comparable with the 90-day data shown in figures 2 and 3. (In figure 4, D denotes decompression and PE1 and PE2 denote past exposure of one and two subjects, respectively.) Again, the set of curves at the left shows the results of preconfinement training. Compared with data from the 90-day subjects, the learning is more rapid and the curves are smoother and more stable. For the Philadelphia no-delay condition, a reasonable extrapolation of the curve beyond the end of training would coincide with the actual confinement data; no performance decrement is present. However, extrapolation of the two-delay curve would yield scores higher than those actually achieved during the first days of confinement. This performance decrement lasted until at least the fifth day and indicated that the group performance was adversely affected by nitrogen narcosis, other conditions of the confinement, or some combinations of these factors.

On days 2 to 14 of the study, each subject was tested twice: Once in the morning (approximately 7 to 9 a.m., denoted by a) and again in late afternoon or early evening (approximately 5 to 8 p.m., denoted by b). Normal diurnal variations were expected to cause performance scores to be lower in the morning than in the afternoon or early evening. The group means for each session were compared with the means of the preceding session. Performance on the no-delay condition remained high throughout the study, and no diurnal variation was evident. For the two-delay condition, the test did measure diurnal group performance change in the expected direction at 19 of the 26 possible comparison

points during the 14-day confinement. The 26 comparisons were then made for each subject individually, and these data for all six subjects were combined in a chi square test. The result is significant at the 1-percent level of confidence.

A classical problem in evaluating the results of performance testing during long-duration confinement studies is that a failure to observe decrements means either that there were no decrements due to the stress or that decrements did occur but the test instrument was not sensitive enough to measure them. Evidence supporting one explanation rather than the other is usually lacking. The reason for discussing the Philadelphia results is that both the performance decrements measured during the early days of confinement and the diurnal performance variations give evidence that the short-term memory test was sensitive to stress. Since a reasonable degree of test sensitivity has been demonstrated, it is probable that for tasks similar to the one described here, stresses such as those experienced by subjects in the 90-day confinement do not produce marked performance decrements.

A troublesome fact, however, is that the performances for three subjects in the 90-day study were similar, but that of the fourth subject was substantially different and did show a decline during confinement. The deviant subject's performance had been quite good prior to the rate change, was reasonably good on the first test session at the higher rate, and was followed by a precipitous drop to an extremely low level for the two-delay condition only. The reason is not apparent from available records. It seems to have been caused either by a loss of motivation or, more likely, an error in test procedure.

An additional comparison of the 90-day study with the Philadelphia study showed marked differences in the subjects' attitude toward the test. The 90-day subjects' group rating for the study gave RATER a desirability ranking of 40 in a list of 57 items (1 = high, 57 = low). This ranking was judged to represent a "fair" level of acceptability. At the end of the Philadelphia study, subjects ranked the seven major experiments and the performance test received a mean rank of 2.3. This rating occurred despite the fact that these subjects were given more test sessions and within a much shorter period of time. Two factors seem most important in accounting for the differences in acceptability: (1) in the Philadelphia test, the subjects actively competed among themselves for high performance scores throughout the study, whereas such competition among the 90-day subjects was less apparent, and (2) most of the experiments in the Philadelphia study were uninteresting for the subjects and some were also physically painful, whereas most aspects of the 90-day study were less unpleasant. The Philadelphia subjects' better acceptance of the test probably contributed to the more rapid learning and more stable performance seen in that study.

The authors would like to use this test again in some future long-duration confinement study. However, three major changes would be made. First, testing would not be given more often than once each week in order to encourage a more favorable subject attitude toward the test. Second, on those days when the test is given, a larger amount of data would be collected to improve the stability

of measurement. And third, testing would be given twice on test days, once in the morning and again in the afternoon, so that diurnal variation comparisons could be made.

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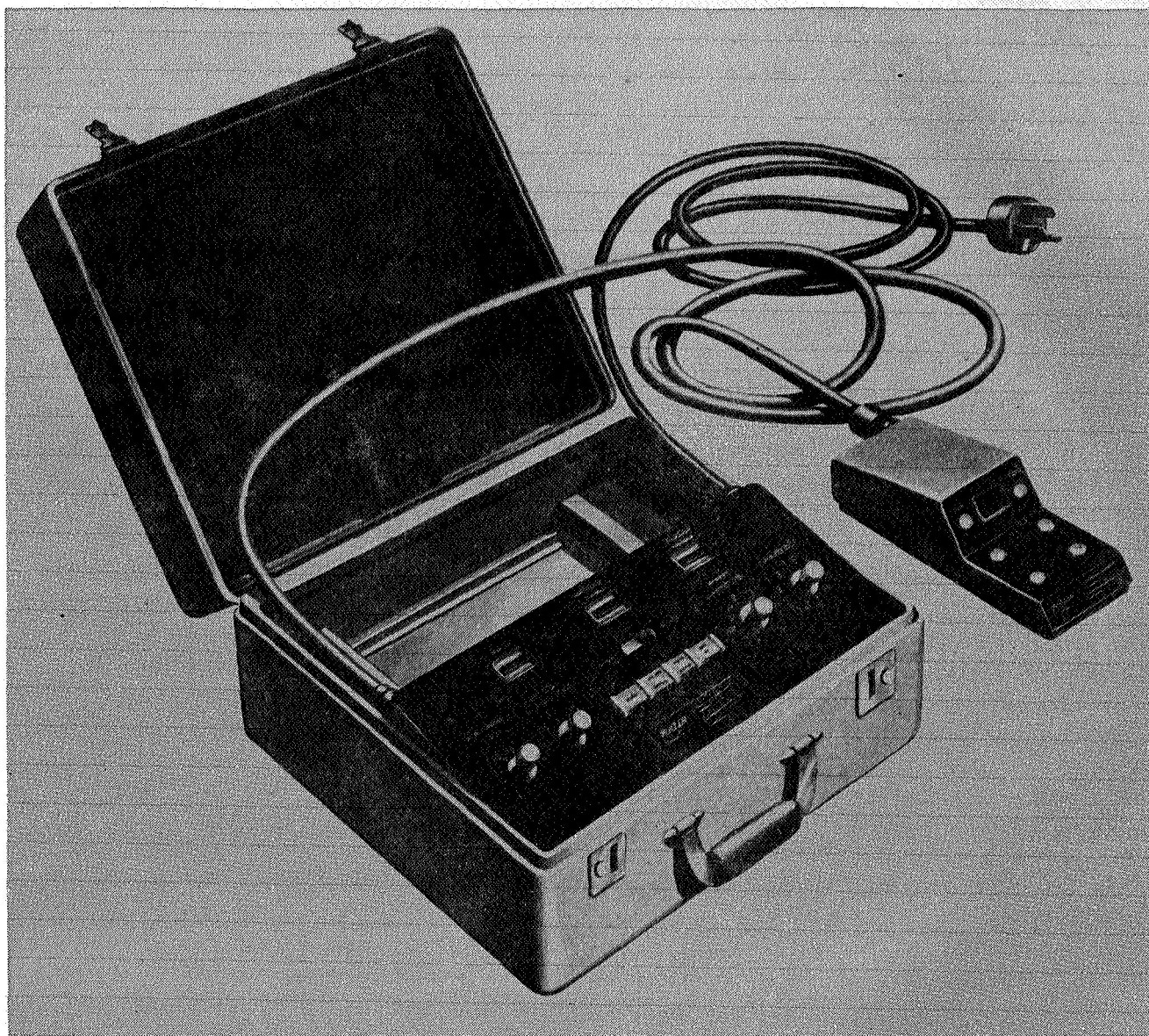


Figure 1.- The Response Analysis Tester (RATER).

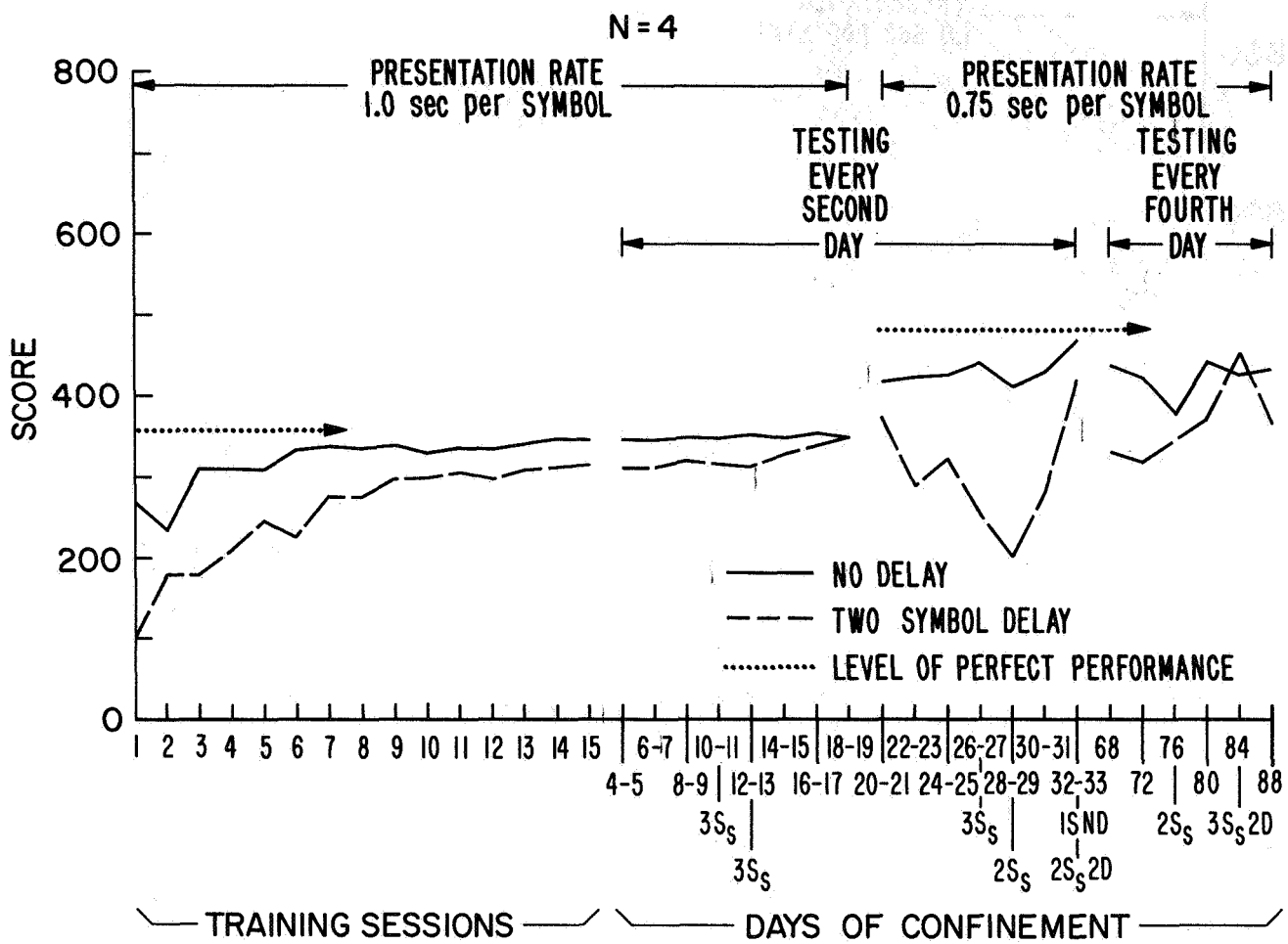


Figure 2.- Mean performance of four subjects on the short-term memory test.

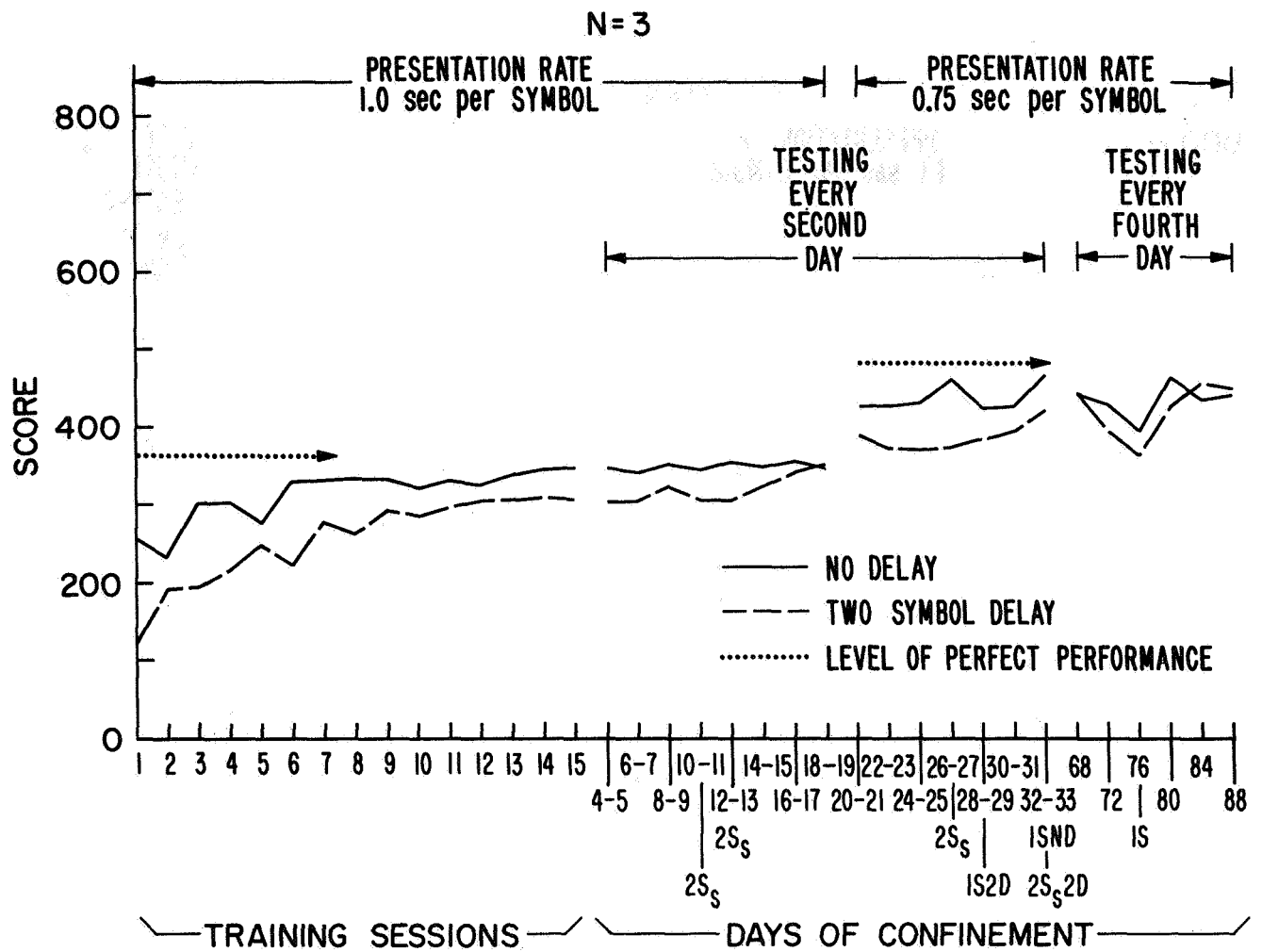


Figure 3.- Mean performance of three subjects on the short-term memory test.

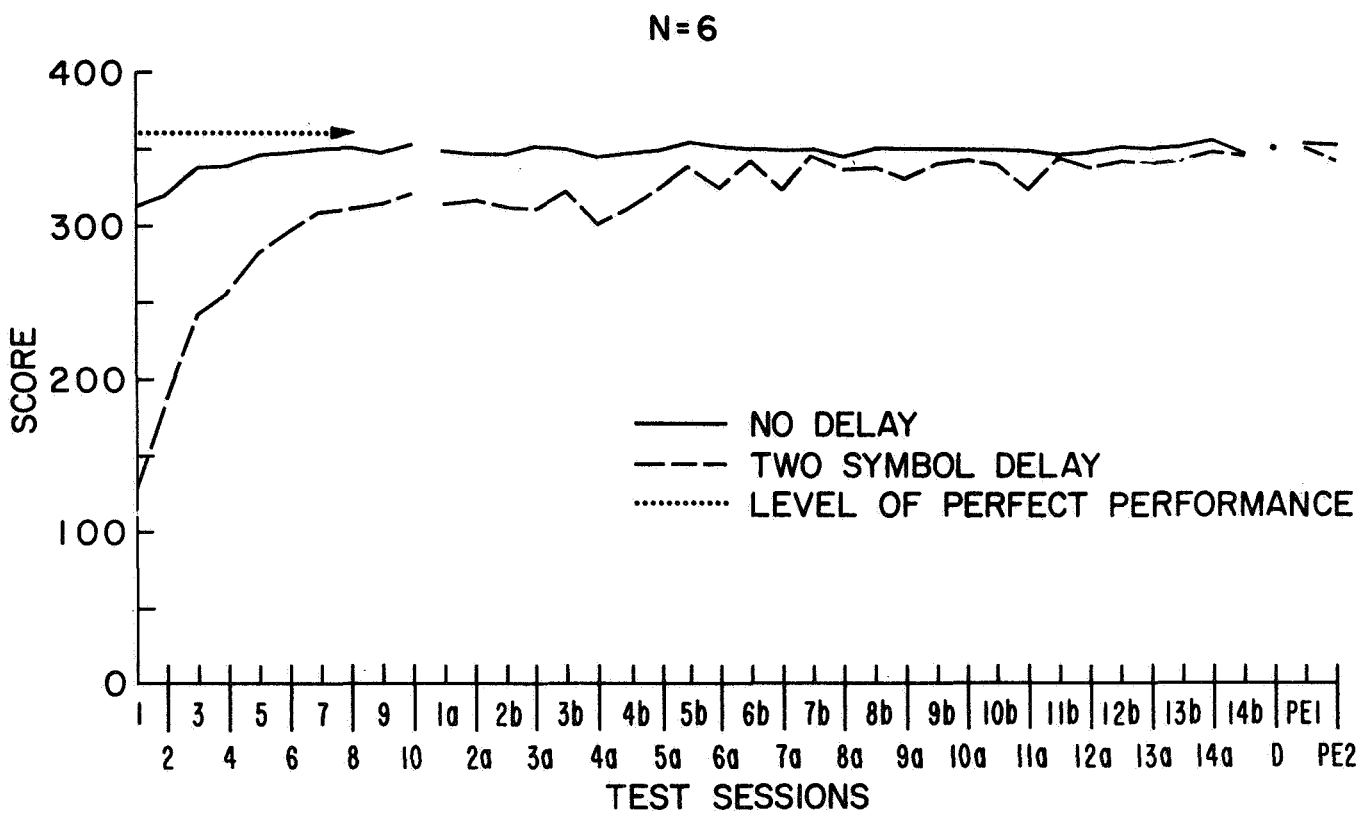


Figure 4.- Mean performance of six subjects on the short-term memory test.

NON-INTERFERENCE PERFORMANCE ASSESSMENT (NIPA)

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McDonnell Douglas Astronautics Company

SUMMARY

Conventional psychological testing techniques (such as paper and pencil tests) which attempt to obtain social and emotional information have a history of negative reactions on the part of subjects exposed to them. One of the original goals of this program was to develop unobtrusive methods (in contrast to intrusive methods) of obtaining social and emotional data from crewmen on the 90-day Space Station Simulator (SSS) test by visually and aurally observing behavior. The object was to avoid the resistance produced by intrusive measurement and its concomitant effect on the data being gathered. However, unobtrusive observation means that crewmen must be completely unaware of observations being made. This was not possible because MDAC established the policy of giving as much information as possible to the crewmen about all aspects of the program. Thus, the title of NIPA is accurate in the sense that the program was conceived to be non-interfering rather than unobtrusive; i. e., cooperation of the subjects was not required or desired. Although they would be aware that cameras and microphones are installed in the SSS, crewmen would be able to carry on their programmed tasks (and other behavior) without interference by the NIPA staff. The crew would also receive a number of intrusive tests of the paper and pencil variety. Ultimately the objective was to develop an observational methodology which would eliminate the need for intrusive testing methods where social and emotional data are desired in operational situations. Thus, MDAC views the NIPA study as a test of methodology and not as a means for contributing substantively to theoretical constructs in individual or social psychology.

EQUIPMENT AND PROCEDURE USED

Equipment

An observer station for NIPA was added adjacent to the communications monitor position in the SSS operations room. The NIPA observer used the TV monitors at the communications console showing the chamber interior as picked up by five cameras in fixed positions onboard. In addition, an auditory capability was provided so that the observer could listen to the onboard microphones as well as intercom conversations between the inside crew and outside staff. By day 31 a remote repeater station was constructed on the second floor of the space laboratory. It essentially repeated the video and audio capabilities of the initial NIPA station. Recordings by the NIPA observers at both stations were entered into a teletypewriter producing a punched paper tape compatible as a computer input (see fig. 1).

The audio capability for NIPA was actually completed during the first week of the test. It became immediately obvious that the system was not designed to the requirements for NIPA observations. Background noise in the chamber made it virtually impossible for the NIPA observer to hear what the crewmen were saying. Installation of audio filters and other circuit modifications were attempted outside the chamber. After a crewman lowered the microphone hanging over the table used for eating/recreation, it was concluded that satisfactory pickup of crew conversations could occur there. For the remainder of the test NIPA observers limited their observations of verbal data to that area. Despite these and later "fixes", the audio quality continued to tax the limits of observer auditory perception throughout the test, except for intercom conversations. A gross subjective judgment by NIPA observers indicates that about 60 percent of the onboard verbal interactions were understood and recorded.

Additional equipment was provided in a room adjacent to the remote station to conduct observer reliability test and training sessions. Video tape recorders, TV monitors, and audio equipment made it possible to tape the information being presented to the NIPA station at any time. Thus, segments of crew action were recorded and established as stimulus standards for presentation in observer reliability test sessions (see fig. 2).

Procedure

The NIPA observer had to record three classes of information: (1) verbal interaction data, (2) the physical locations of crewmen with associated activities, and (3) other observer judgments. Intracrew verbal interactions as well as conversations with outside staff members were recorded.

The observer identified and recorded who initiated and who received each interaction. In addition, he made a judgment of verbal content based on four categories derived from the 12 Bales Interaction Process* categories (see fig. 3). The observer's orientation was to assess the verbal content for the presence of emotional affect. He attempted to determine whether the receiver of the message treated the affect as positive (liking, approving, etc.) or negative (disliking, criticism, etc.). If no affect was detected, the observer classified the statement as either asking for information or giving information. Thus, if Terry asked information of Steve three teletypewriter keys (appropriately labeled for NIPA) were depressed in the order: QAW (see fig. 4).

The physical locations of crewmen were recorded on the teletypewriter every 2-1/2 minutes in terms of nine preselected areas in the chamber. In addition, certain specific locations were identified to indicate crew time on special equipment such as the Langley Complex Coordinator or actually watching the onboard TV monitor (see fig. 5).

*Bales, R. F. Interaction Process Analysis, Cambridge, Mass.: Addison-Wesley, 1951.

The NIPA observer was also required to record other assorted judgments including a subjective assessment of workload (labeled "task-press") on a seven-point scale and some psychosomatic complaints, if verbalized (see table 1).

NIPA observers monitored crew behavior daily. For one period early in the test, monitoring was done continuously from 0700 hours until 0100 hours the following morning. However, manpower requirements made it necessary to reduce the monitoring time to the segments of time when four crewmen were up (i. e., during nonsleep periods). This change was consistent with a pretest decision to place primary emphasis upon these periods. As a result, the data discussed here were collected daily during the hours 0600 to 1400 and 2000 to 2400.

DATA REDUCTION

The data reduction effort for NIPA reduced large amounts of raw data to permit the testing of relationships among the psychological variables under study. As mentioned above, the raw data are measurements of crew behavior made on a continuous basis by observers looking at closed-circuit TV monitors which display the interior of the SSS.

In general, the scheme employed two teletypes, one at the initial and the other at the remote observation station, to record the behavior of the onboard crew by audio and video links. Observers used the teletypewriters to produce a character "string" which is essentially a serial record of crew behavior. The string, recorded on paper tape, is read into a computer which in turn "reduces" the data into time intervals of 20 minutes, 4 hours, and 1 day. The computer program can also produce a protocol.

The NIPA flow is illustrated in fig. 6. Three distinct phases are shown: data collection, data reduction, and data analysis. The teletypewriter entries are coded observations of the crew which conform to the variables mentioned earlier. The teletypewriter had specially labeled keys which conformed to these variables. Paper tapes containing approximately 4 hours of observer entries represented the output of the data collection base. These paper tapes formed the raw data "string" to be reduced by the data reduction phase.

Data reduction was done on a time-sharing computer. The raw data paper tape was read into a remote tape reader. The program produced a magnetic tape copy of the paper tape and a printout of the frequency matrices for each individual tape. These frequency matrices are directly related to each type of measure and provided the numerical values of the indices that were used in the analyses.

ANALYTIC TECHNIQUES

The most basic level of analysis requires statistical correlation and multiple regression analysis of the variables associated with NIPA and the intrusive (paper and pencil) test variables. Graphical presentation of data is also employed. Although a program exists to perform correlations, at present the NIPA data are not completely reduced to the point where data input can be made to it. Therefore, correlations are not available for presentation. However, at this writing data are summarized for a number of indices for each day of the run during four-man-up periods, making it possible to present some graphs showing group results (i. e., not individual crewman results). It is emphasized that these results are based on a preliminary analysis of one data point for each day for each applicable variable and that analysis of the data in terms of 20-minute summaries is in progress. The data prior to day 31 in the graphs that follow should be considered unreliable because:

- A. From day 1 through 15, no data were gathered.
- B. From day 16 through 30, the NIPA observers and staff were learning the refinements necessary for the new data collection method.
- C. A number of ground rules or conventions were created or changed during that period affecting how typical or marginal cases were to be recorded.
- D. Observers were receiving their first training with the complete complement of NIPA equipment.

RESULTS

Figures 7 and 8 deal with verbalized emotional affect expressed in ratios. Verbal statements identified as containing affect were recorded as either positive or negative. The total number of positive and negative statements represents total affect for a given duration. The number of positive statements out of the total affect may be expressed as the positive affect ratio, as follows:

$$\text{Positive Affect Ratio} = \frac{\Sigma +}{(\Sigma +) + (\Sigma -)}$$

Similarly,

$$\text{Negative Affect Ratio} = \frac{\Sigma -}{(\Sigma +) + (\Sigma -)}$$

Figure 9 is a measure of the extent to which the crew members were geographically separated from each other. The ordinate is labeled psychological distance. If one crewman is standing in the equipment quarters and another is in the crew quarters, they are separated by a measurable physical distance. However, if the bulkhead door separating the two is closed, the psychological distance between the crewmen is significantly greater than if the door is open. Therefore, a scale was developed to measure this and similar psychological distances between the areas shown on the floor plan in fig. 5.

CONCLUSIONS

The three graphs selected for presentation here show tentatively that the NIPA methodology is sensitive to changes in social and emotional states, especially at psychologically significant points during the test. Of interest is that not all the paper and pencil tests detected these changes.

It is known that certain interpersonal problems existed among the crew from days 60 to 70. The positive affect ratio generally shows a dip during this period while the negative affect ratio shows a rise. Similarly, group dispersion shows a rise. These are all in the predicted direction as reflections of interpersonal problems. It is expected that an even clearer picture will be presented when the data are graphed for individual crewmen and when our correlational analysis is complete.

The fact that the NIPA method provides data on a continuous real-time basis provides advantages that become apparent in dealing with graphical data: (1) the data are sensitive to short-term changes and (2) events are detectable that occur between intrusive test administrations. Short-term change detection might be possible with paper and pencil (intrusive) testing if administrations were very frequent. However, this is not feasible because of the following reasons:

- A. Crew reaction to being administered intrusive tests daily would certainly be negative.
- B. Time and cost of test administration would not be justified.

Table 1
OTHER OBSERVER JUDGMENTS

Category	Recording ¹	How Often ²
Task-press/workload	7 scale	1 per hour
Bulkhead door, open or closed	2 scale	Concurrently
Complains of headache	3 scale	1 per shift
Complains of stomach upset	3 scale	1 per shift
Complains of fatigue	3 scale	1 per shift
Complains of depression	3 scale	1 per shift
Other complaints	3 scale	1 per shift
Problem-solving and creative/ innovative behavior		Concurrently
Touch equipment		Concurrently
Touch persons		Concurrently

NOTE 1: Recording scale as follows

<u>7 Scale</u>	<u>3 Scale</u>
1 Overwhelming - cannot be done	1 Not mentioned
2 Extremely heavy - can be done	2 Mentioned
3 Moderately heavy - can be done	3 Severe
4 Average	
5 Moderately light	<u>2 Scale</u>
6 Very light	1 Open
7 No task requirement	2 Closed

(This judgment is made from the
crewman's viewpoint.)

NOTE 2: The requirement of one per shift is minimal. Additional
recordings should be made as needed.

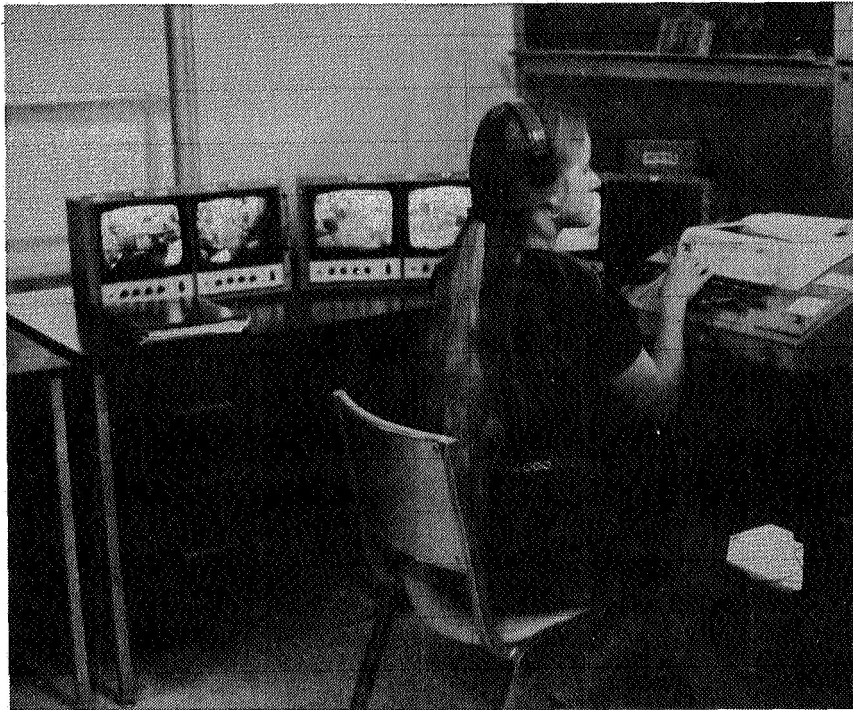


Figure 1.- Remote NIPA station.

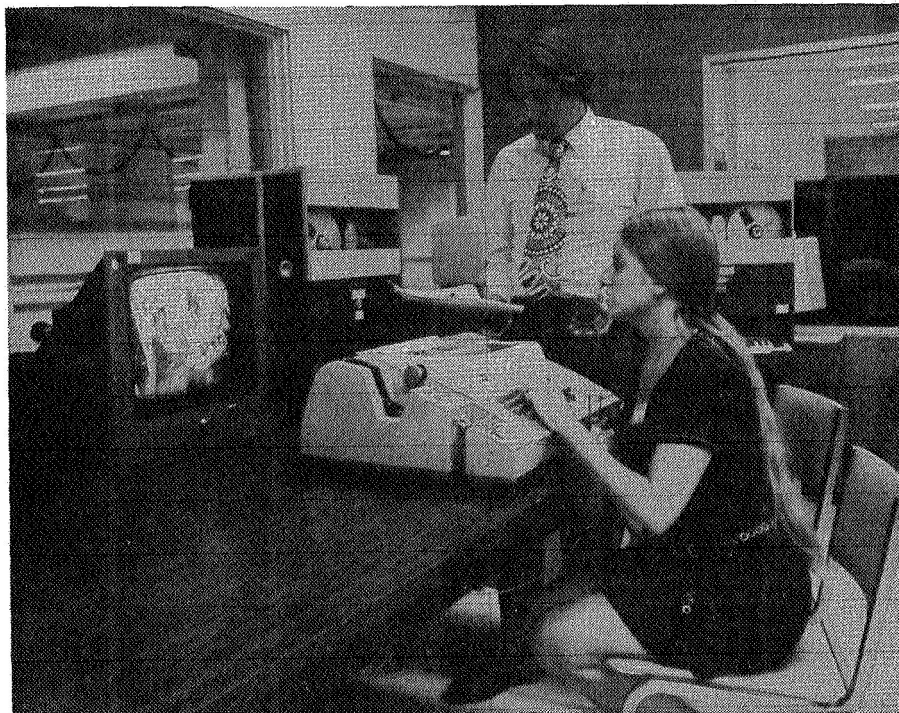


Figure 2.- NIPA observer reliability test/training session.

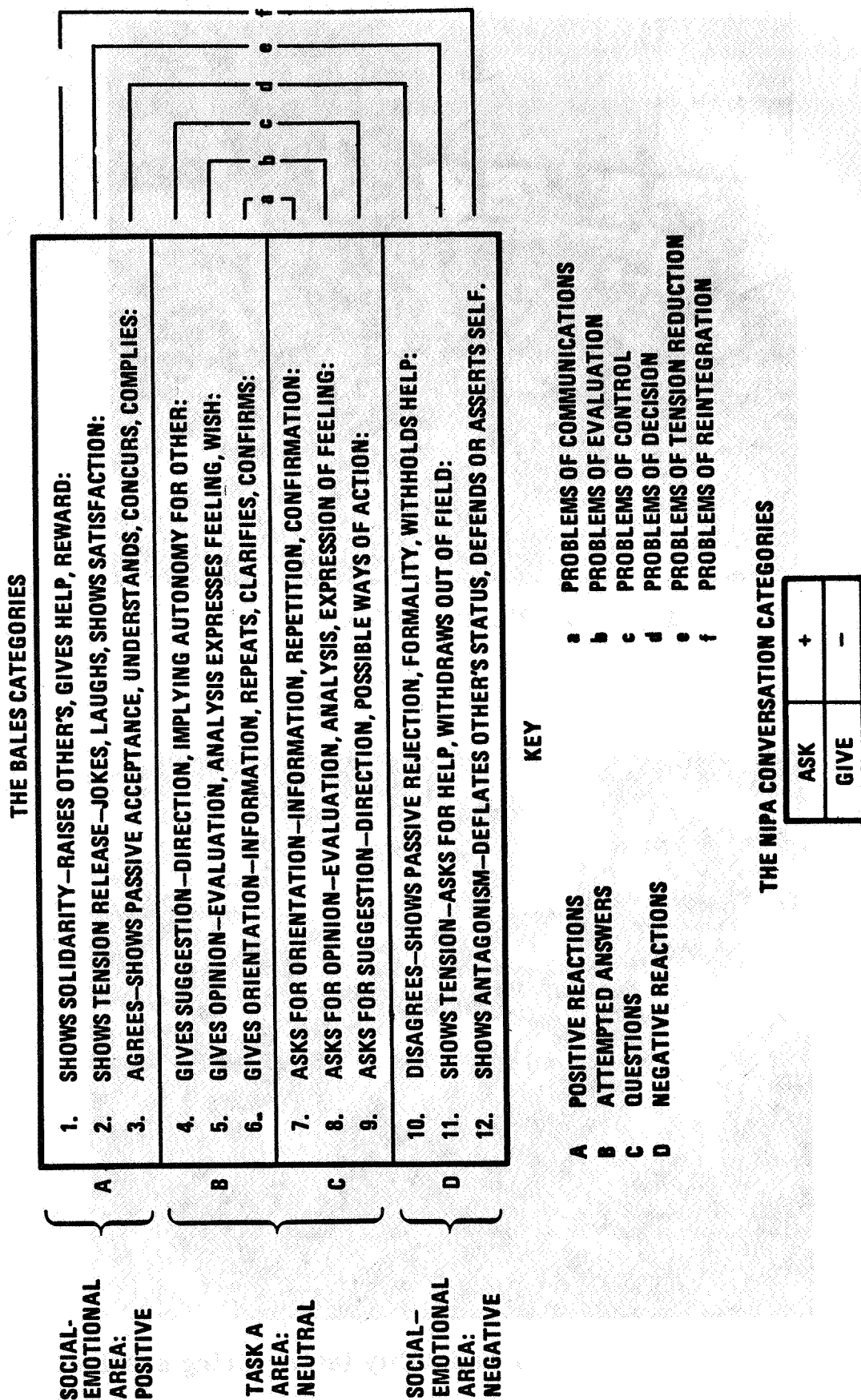


Figure 3.- NIPA conversational categories collapsed from the Bales system.

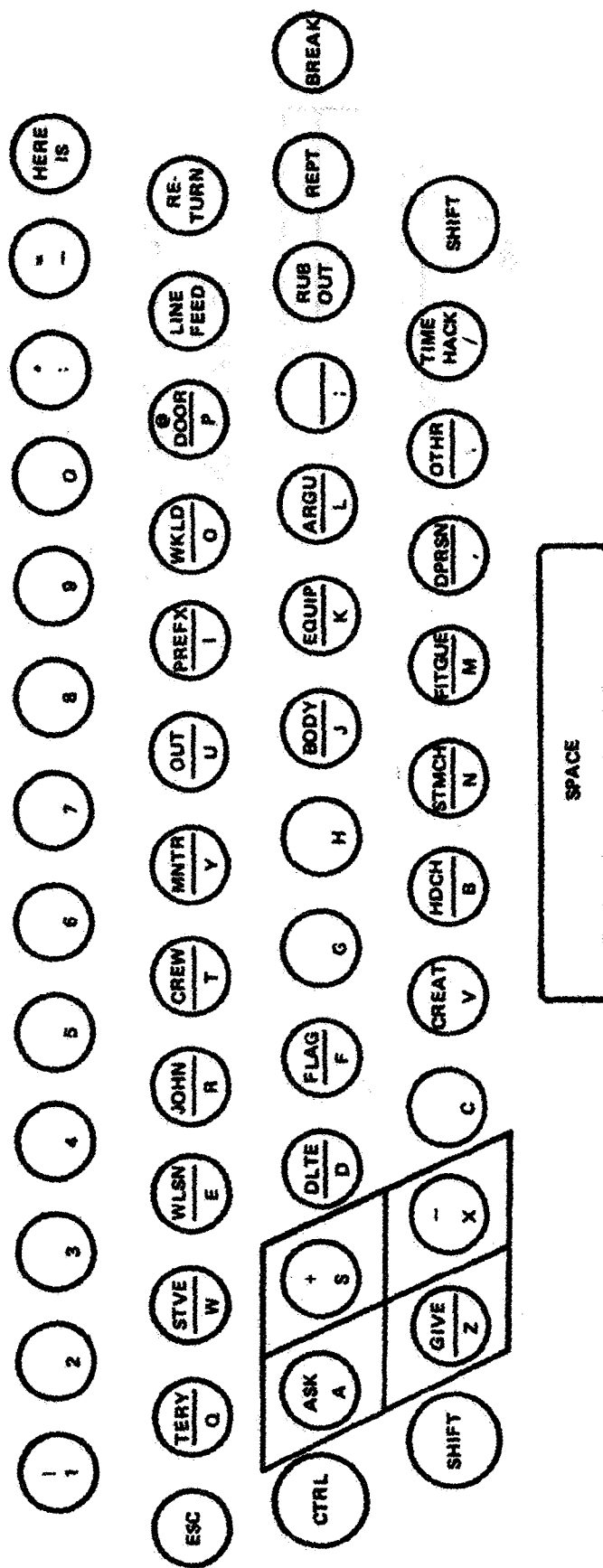
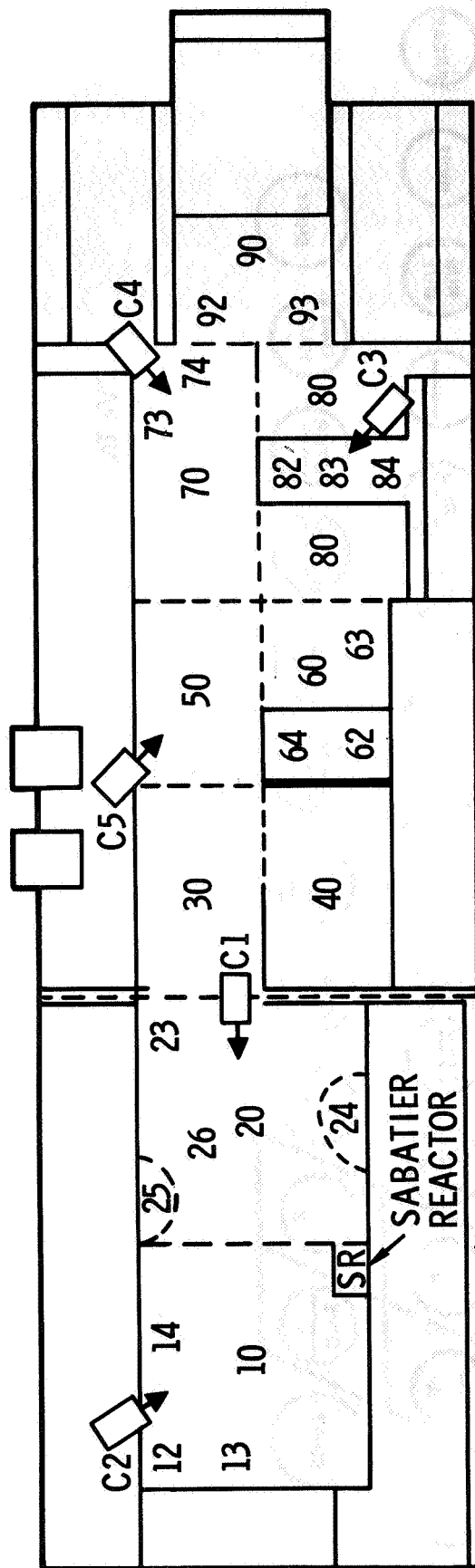


Figure 4.- Teletypewriter keyboard labeled for NIPA.



A LIST WAS PROVIDED TO THE OBSERVER FOR IDENTIFICATION

Figure 5.- Space station simulator floor plan labeled for NIPA observations.

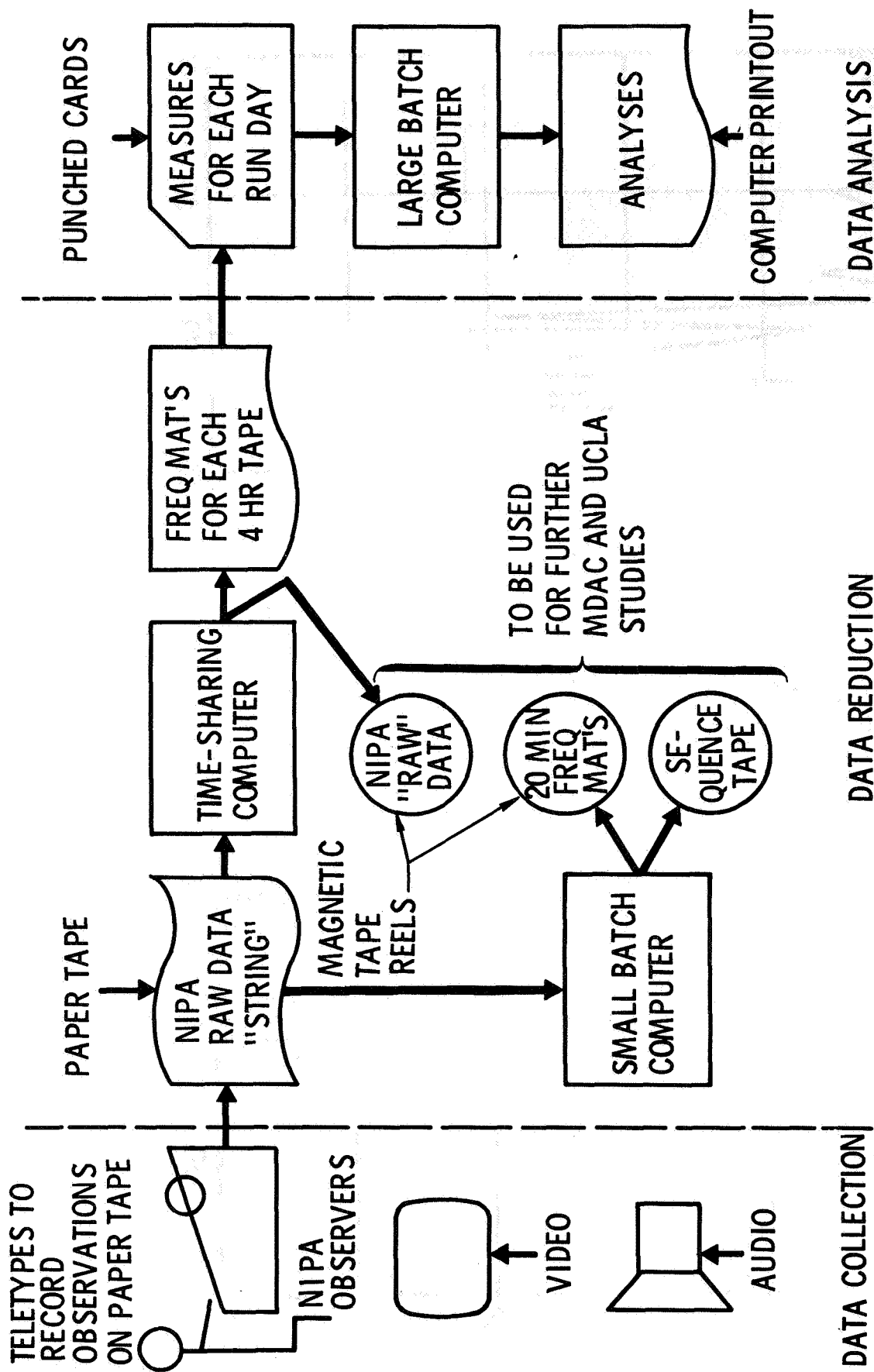


Figure 6.- Flow diagram of NIPA data collection, reduction, and analysis.

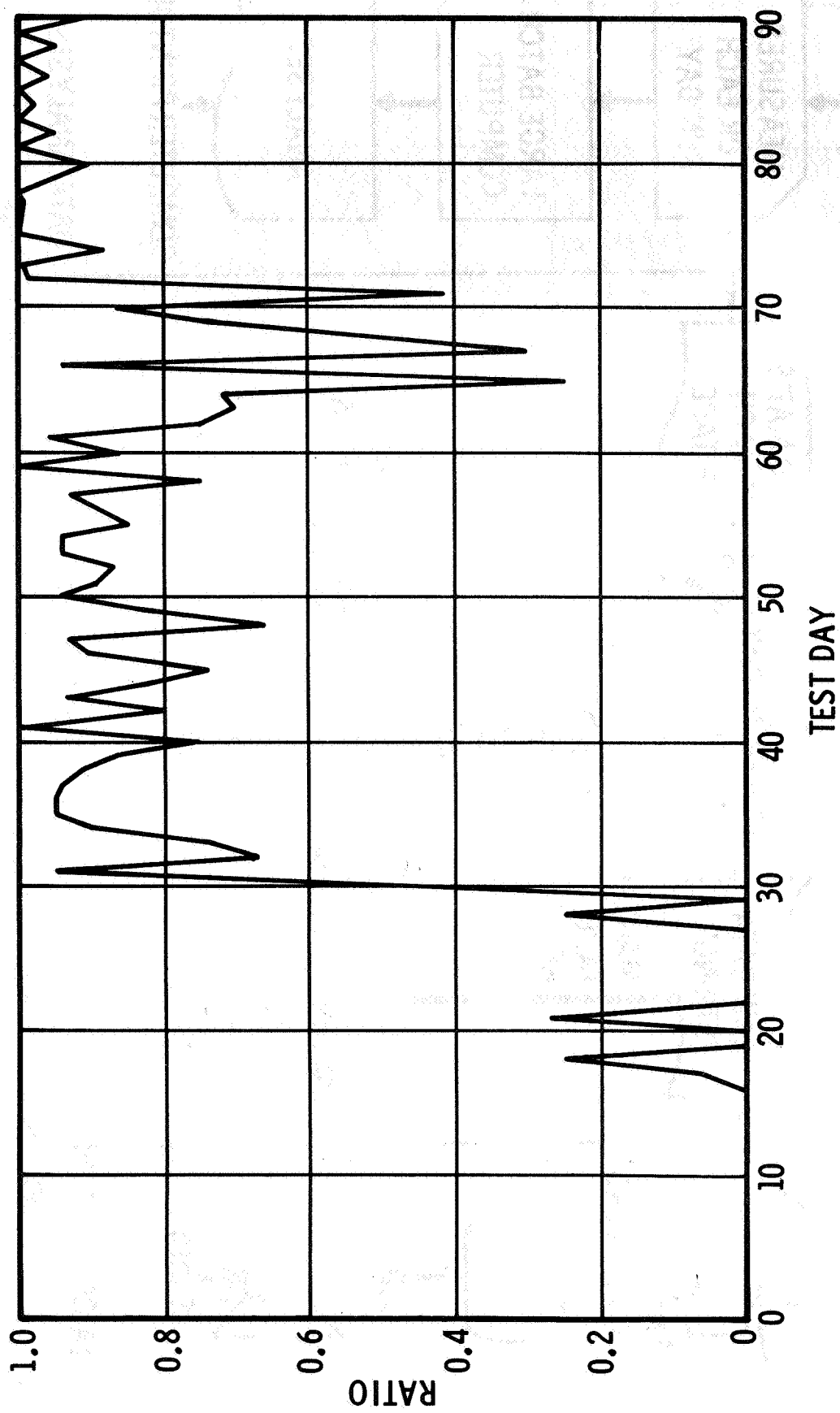


Figure 7.- Positive affect ratio.

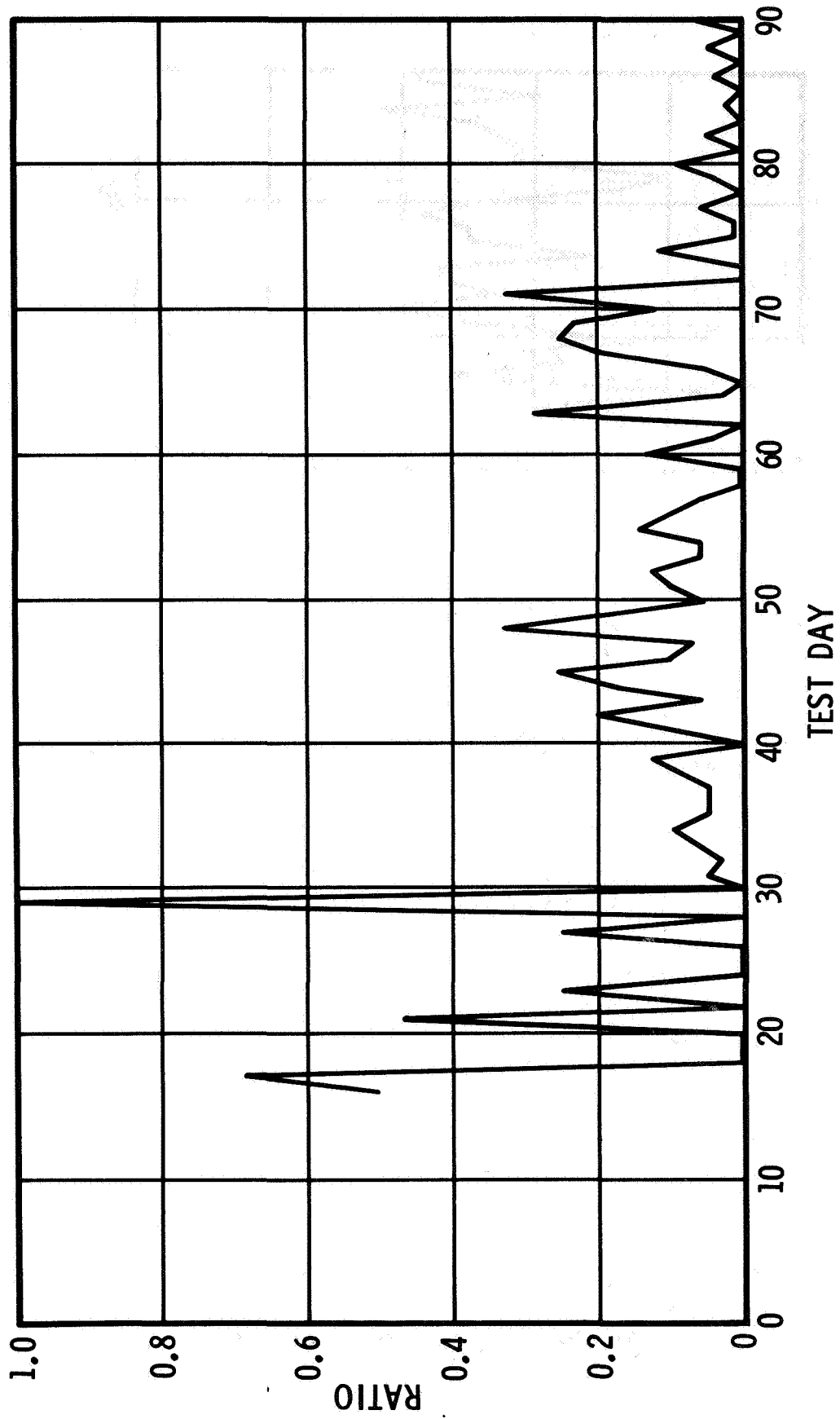


Figure 8.- Negative affect ratio.

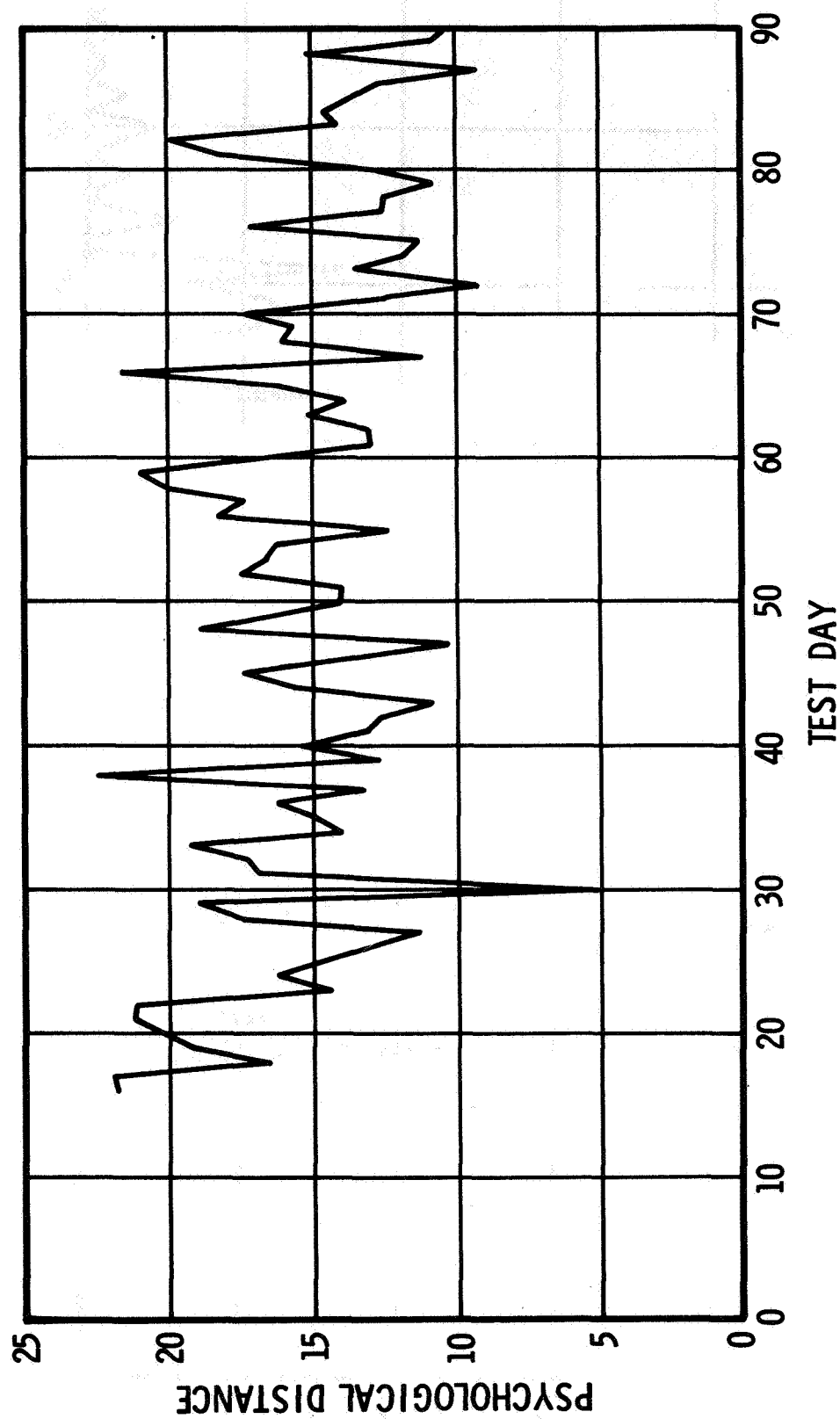


Figure 9.- Group dispersion.

PSYCHOLOGICAL ASSESSMENT OF CONFINED CREWS

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INTRODUCTION

Many of the hardware alarms during the 90-day run resulted from failures in measurement instrumentation, but most of the engineering papers on the mission have been able to rely on established, reliable, and valid assessment procedures. In our assessment of the psychological and social integrity of the crew, however, the experiment is as much concerned with evaluating the measuring instrument as with evaluating crew behavior.

Psychologists are seldom subtle in their efforts to assess and categorize their human subjects. They usually require a subject's full attention and cooperation — whether filling out questionnaires, free associating, or manipulating test equipment. But in a space mission, the psychologist who follows this precedent inevitably creates operational problems. He adds to the heavily scheduled workload of the crewman, and thus his tests generate frustration, antagonism, and a decrement in performance on essential operational tasks. "Nonintrusive" psychological assessment (NIPA) would clearly ease the operational problems for any crew, whether in orbit or not.

Even in other settings, where psychological testing does not interfere with operations, the traditional, intrusive types of psychological measurement have come under recent criticism. At worst, these intrusive techniques alter the object being measured; the very fact that a subject knows he is being evaluated probably changes his thoughts, feelings, and behaviors. Furthermore, psychologists are beginning to realize that these traditional, intrusive measuring instruments are subject to a number of biases such as social desirability, response sets, and evaluation apprehension. The essence of the criticism seems to be that the subject tries to create a false instrument reading. He gives answers which he thinks the psychologist wants to hear rather than what he himself feels to be true. Thus, besides their operational advantages, nonintrusive tests may provide the most valid instruments for psychological assessment.

It would have been tempting to use the NIPA study to provide a narrative, biographical account of the crew experience during the 90-day run. The events in the lives of the crewmen were certainly varied and interesting, and one is loathe to leave them unrecorded. But if the U.S. space program hopes to develop a scientific procedure for identifying and forecasting problems in crew performance, we must abstract those parameters of crew behavior which are most predictive. It is for this reason that we decided to focus the NIPA observer's attention on the physical location of the crewmen, physical movement, and on the task and affective aspects of their verbal communication.

CRITERION PROBLEM

By almost every measurement procedure established in advance of the 90-day test, the crew performed at 100 percent. Although there had to be considerable variance in behavior from crewman to crewman and from day to day, our performance gages did not register differences in the range of task performance that was observed. For instance, we carefully recorded the number of required and recommended tasks completed on each day of the mission. We expected that, as the mission wore on, some of the tasks would not be completed on particularly boring or stressful days. The mission analysis log, however, indicates that essentially every task was completed every day, so that the measurements collected show no variance; they were "wrapped around the peg" for the entire mission (fig. 1).

As may be too often the case, what is wheat for the operational personnel is chaff for the basic researcher and long-range planner. If every day is classified only as a "success," we have no index of which days were merely successful and which were extremely successful. In other words, we have no variance in our criterion variable and hence no criterion variable to predict. The data collected in the NIPA project may well represent some of the most sensitive and innovative predictive variables ever devised in this type of study, but there is nothing to predict. Thus, most of the data analyses are essentially "bootstrapping." We can intercorrelate the various NIPA predictive instruments with other predictive instruments such as pencil and paper questionnaires, medical interviews, and the psychomotor tests on board the simulator. We can correlate all these variables with environmental variables such as temperature, humidity, and noise levels. In short, we shall never know whether our predictive instruments could have spotted serious personal or interpersonal difficulties before they created a serious problem for operations because the kinds of problems we would like to be able to predict were conspicuously absent from this 90-day test.

THE AUTOCORRELATION TECHNIQUE

Traditional methods of psychological analysis attempt to discriminate among subjects, and the traditional form of correlation would predict which crewman would be likely to perform best, which second best, and so forth. With only four crewmen, however, this type of analysis is inappropriate. Thus, a crew of four does not provide a large enough statistical base to make reliable, statistical judgments on crewman evaluation and crewman selection.

However, since the crew did spend 90 days aboard the simulator, we can study the covariation among measures across time - often called the autocorrelation technique. Conclusions from these analyses are relevant to problems which arise after the crewmen have been selected. The generalizations which will hopefully emerge from these data analyses will help us to detect personal and interpersonal problems which occur after a crew has been selected and has started work on the mission. We can look for nonintrusive correlates of fatigue, frustration, boredom, and psychological tension through time. (See fig. 2.)

THE PREDICTOR VARIABLES

We made a number of simplifying assumptions for this first illustrative data analysis. First, we focused on those periods during the day in which none of the four crewmen were scored as sleeping. Secondly, we focused on changes that occurred from day to day; we generated a single number for each crewman per day to summarize his activity for that day. Furthermore, we have limited our initial attention to events that occurred after day 31 -- the day on which the UCLA observers went on-line at the remote observing station.

Thus, for each crewman we have a number for each of the last 60 days summarizing the daily activity during periods in which all four crewmen were not asleep. A measure of privacy was obtained by scoring the percentage of spatial observations in which each crewman was alone in one of the coded physical areas of the simulator. We have a measure of physical dispersion which reflects the total distance of one crewman from the other three crewmen. There is a measure which reflects the average length of movement when a crewman moves from one area of the simulator to another and another measure of physical activity which simply reflects the total number of movements made during the observed period.

Each 2.5 minutes, when the observer noted the physical location of a crewman, he also indicated in which of nine activities that crewman was engaged. We can get a rough index of time spent working on tasks by computing the percentage of all judgments which were coded as task activity. From the communication monitors' log and from on-line observation by mission analysis personnel, we have a figure representing the total number of times a crewman was asked to perform a task during time scheduled as free time or recreation in the time line. From the same source we have a measure of the duration or amount of time spent on the tasks described above.

RESULTS

The three task variables are intercorrelated. (See fig. 3.) Time on task correlates 0.26 with intrusions and 0.47 with duration. Intrusions correlate 0.68 with durations. These three task measures represent, operationally, two independent measurement procedures. The NIPA observer on the remote station judged every 2.5 minutes whether or not a crewman was engaged in task activity. Independently, down in the control room, the communication monitor recorded in his log, or a mission analysis observer recorded in his, the number and duration of requests for task activity during scheduled recreation time. Thus, these correlations among the task measures are not trivial because the intrusions and durations data were collected at the control station by the communications monitor and mission analysis personnel, whereas time-on-task measurement represents the cumulative judgments of the UCLA trained NIPA observer at the remote station. These correlations serve to validate the reliability and validity of both the NIPA observers and the data reduction process.

THE SEARCH FOR A NONREACTIVE CRITERION OF CREW PERFORMANCE

The fact that the crew performed at 100 percent on all our measures of task performance illustrates the reactive nature of these intrusive measurements. The crewmen were aware that operational personnel were assessing whether or not they completed all the recommended and mandatory tasks. The crew's knowledge that they were being evaluated in this manner also contributed to the fact that they completed all tasks every day.

Postegress interviews with the crewmen indicate that they did feel that their performance varied considerably from day to day — even though this variability in task performance was not reflected in any of the reactive measures set up before the 90-day run. But are there any residues of their performance remaining at the end of the 90-day run which might reflect this undetected variance? Ideally we would want to find some regularly scheduled meter reading, dial adjustment, or other activity which required some degree of perceptual, mental, or motor ability and attention to accomplish. Furthermore, this would have to be an activity on which the crew did not expect to be evaluated. If our speculation is correct, the crew was motivated to perform at maximum on those variables monitored by the off-board crew.

One daily task which could be examined is the daily computer feedout by the crew. This output was monitored only for content, but variance in typographical quality is highly likely. The computer, however, was not programed to note such initial errors and only recorded the final corrected message. Furthermore, the data link between the simulator and the computer appears to have added a certain amount of noise to the transmission, which might be hard to differentiate from crewman error. Finally, the software of the computer cleaned up some typographical errors before the data were stored.

An alternative and comparable possibility would be to look at the quality of the entries in the diaries of the individual crewmen. This is probably an intellectual and motor performance which varies in amount and quality. Soviet space scientists (ref. 1) have examined the handwriting of cosmonauts during space flight. German scientists (ref. 2) report deterioration of fine motor movements in handwriting as a function of noise levels. The privacy of the crewmen can be respected if we ignore what is said and focus on style of expression. Thus we might look for grammatical errors, crossouts, poor penmanship, incomplete sentences, number of abbreviations, and so forth. Joan Ranere, the training director for UCLA on the 90-day test, devised and quantified 11 such variables for each of the last 60 days of the mission. Correlational and factor analyses of these indices for each crewman indicate that several of these quantifiable writing factors vary together from day to day over the last 60 days of the test. In particular, three of the variables seem to form a reliable index for each of the four crewmen which may represent assessment of the intellectual, perceptual, and motor acuity of the crewmen. Percentage of abbreviated words, percentage of incompleted letters, and percentage of incomplete sentences are significantly intercorrelated for each of the four crewmen. (See fig. 4.) It should be stressed that these three measures represent distinctly separate aspects of writing. Incomplete letters involve only penmanship, a motor ability;

abbreviations are a form of shorthand; incomplete sentences are grammatical, stylistic, and syntactical. For example, using incomplete sentences does not imply that the author will abbreviate his words. The fact that these three measures are intercorrelated for all four crewmen gives us some confidence that the quality of the transcriptions in the diaries does indeed reflect a nonintrusive intellectual, perceptual, and motor performance assessment.

Before the 90-day test, most of us anticipated that confinement, stress, and hardware crises would constitute the greatest threats to psychological and social integrity. We predicted that performance would deteriorate on those days with a heavy task load and/or poor environmental quality.

UCLA personnel who monitored the run formed a quite different clinical impression a little more than halfway through the run. It was our intuition that the major problem confronting the crew was boredom. If it is indeed boredom, lack of novelty, and sensory deprivation which created the greatest problems for psychological and social integrity among the crewmen, then we would expect the greatest decrements in intellectual, perceptual, and motor ability on those days when the task load was lightest.

Thus, these different intuitions about the sources of trouble for the crew make different predictions for the relationship between task load and performance on our unobtrusive measure of mental and motor acuity. The crisis-fatigue-stress model predicts a negative correlation between task load and quality of diary transcriptions; the boredom model predicts a positive correlation between task load and quality of diary transcriptions. (See fig. 5.)

The data suggest the boredom model. All three of our measures of task pressure are positively correlated with transcription quality. It was on the days that the crewmen were most harassed by task demands that they used the fewest abbreviations, recorded the fewest incomplete letters, and transcribed the fewest incomplete sentences — that is, were most careful and complete in their diary entry. According to this measure of task performance, the crew was at its best when the task load was heaviest.

This interpretation is supported by the fact that transcription quality tends to increase on days when the crew took long trips around the simulator. All six correlations among our two measures of length of movement and the three transcription quality indices are positive and range from 0.09 to 0.34. Again, it appears that crew performance was at its best when they were most taxed.

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CALIBRATION OF PERFORMANCE MEASUREMENT

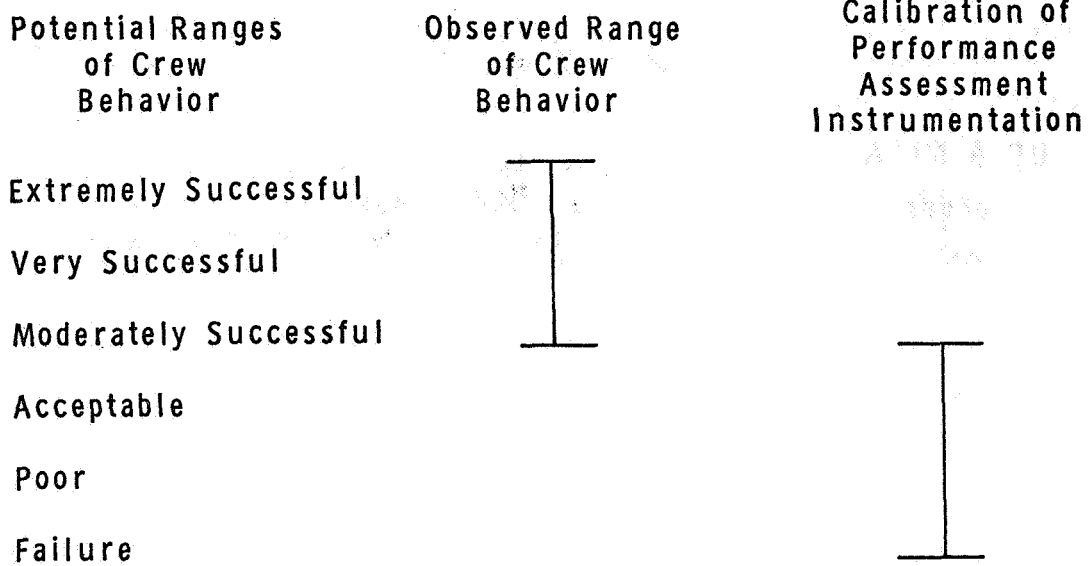
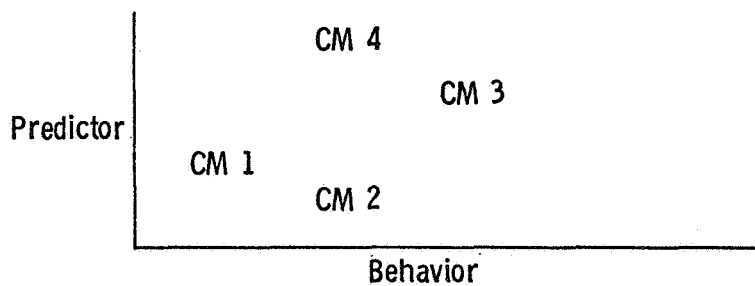


Figure 1.

AUTOCORRELATION

Traditional correlation: Covariance between variables across a number of individuals



Autocorrelation: Covariance between 2 variables across a number of times

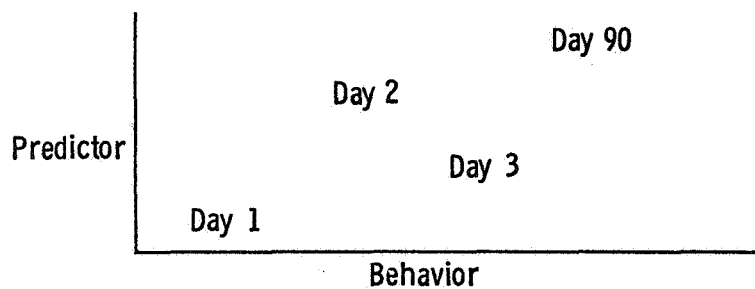


Figure 2.

CORRELATIONS AMONG TASK VARIABLES

		1	2
UCLA NIPA			
Observer at	1. Time on task		
Remote Station			
	2. Task intrusions	.26	
MDAC Observers			
at Communication	3. Duration of		
Monitor Station	intrusions	.47	.68

Figure 3.

CORRELATIONS AMONG ASPECTS OF DIARY TRANSCRIPTIONS

(1) Abbreviations				
(2) Incomplete Letters				
(3) Incomplete Sentences				
	Crewman 1	Crewman 2	Crewman 3	Crewman 4
(1) & (2)	.34	.12	.67	.36
(1) & (3)	.16	.06	.30	.35
(2) & (3)	.21	.23	.44	.38

Figure 4.

CORRELATIONS BETWEEN TRANSCRIPTION QUALITY
AND TASK LOAD

	Time on Task	Duration of Intrusions
Abbreviations	-.36	-.10
Incomplete Letters	-.19	-.09
Incomplete Sentences	-.21	-.30

Figure 5.

BEHAVIORAL ACOUSTICS - THE IMPACT OF SPACE SIMULATOR NOISE ON CREW MEMBERS

By Lawrence E. Langdon, Richard F. Gabriel,
and Paul A. Abell

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SUMMARY

A multi-faceted program was used to evaluate the effects of Space Station Simulator background noise on the crew members. The main goal was to define limits for the background noise in future long-duration missions.

A 1/2-hour behavioral acoustics test battery was given to each crew member weekly. Two of the crew members showed some temporary reduction in hearing acuity during the 90-day test. One of the crew members became sensitized to the quality of the simulator background noise near the end of the test. No important changes were seen in speech comprehension.

Repeated habitability questionnaires, a post-test questionnaire on noise, and a noise debriefing were used to obtain crew reactions. The living quarters noise, approximately 64 dB(A) (NCA-55), was rated reasonably satisfactory. The equipment area noise, approximately 77 dB(A) (NCA-70), was not well accepted, although crew members spent limited time in that area. Intermittent noises such as pumps and talking were rated as the worst noise problem, especially when trying to sleep.

Specific recommendations based on these findings and assessment of the adequacy of the acoustics test program are provided.

INTRODUCTION

Normal background noise limits are of questionable validity for long-duration space missions because most standards are based on an 8-hour/day exposure and because there may be interactions between noise level and reduced cabin pressure. Furthermore, some temporary reduction of hearing acuity was noted in earlier studies (ref. 1).

Noise-reduction goals were established for the design of the simulator, which consisted of a living quarters area, which had a noise level of approximately 64 dB(A), and an equipment area, at approximately 77 dB(A). The basic function of the behavioral acoustics program was to provide information for future ambient noise specifications by asking the following questions about the present program:

- Were there changes in absolute hearing acuity (threshold) during the conduct of the test?

- Were there changes in speech comprehension?
- Did subjects habituate or become sensitized to the cabin noise?
- What were the crew's attitudes toward the noise?

PROCEDURE

Cabin Noise Measurements

Cabin noise was measured before the 90-day test and three times during the test. In each case, the noises at numerous locations were recorded using a calibrated tape recording system. The recordings were analyzed to determine the frequency spectra and levels (amplitudes) of the noises. This work is discussed more fully elsewhere (ref. 2).

Behavioral Acoustics Test Battery

A three-part behavioral acoustics test battery was given twice before the 90-day test, weekly during the test, and twice after the conclusion of the test. All tests were presented through circumaural earphones, which attenuated the background noise. A pushbutton was provided for crew member responses.

The audiometric test consisted of presenting each of six tones (500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz) to each ear separately. The crew member pressed the response button when he could not hear the tone and released it when he could hear it. This actuated a motor-driven volume control which adjusted the level. The level was continually recorded on a chart, providing a tracing of the crew member's hearing capability.

Speech interference tests consisted of a series of words mixed with recordings of the simulator ambient noise. The crew member used answer sheets containing sets of six rhyme words and checked the rhyme word in each set which he thought he heard. Two types of tests were given. In the first, 50 different rhyme word sets were used to provide a varied sample of speech. The second used the same rhyme word set repeatedly to provide maximum reproducibility of the data. Each of these tests was given twice, mixed with recorded living quarters noise and mixed with recorded equipment area noise. In each case, preliminary tests completed before the 90-day test were used to set the speech level at a point where approximately 50 percent of the words would be recognized correctly. This increased the sensitivity of the tests.

The acceptability or annoyance tests were adaptations of the loudness and annoyance judgment techniques used in rating aircraft flyover noises. Crew members listened to pairs of noises presented serially. A standard sound (random noise filtered to contain equal energy in each octave) was followed by recorded simulator noise. The crew member pressed his response button once if he preferred the first noise, twice if he preferred the second. After

presentation of each pair, the experimenter adjusted the standard noise level based on the crew member's responses, so that he could determine the level judged as acceptable as the cabin noise. This test was also given twice, once with living quarters noise and once with equipment area noise.

Assessment of Crew Attitudes

A habitability questionnaire was given biweekly during the 90-day test. Crew members rated 58 environmental factors on a scale of excellent, good, fair, or poor. Three of these items related to noise levels. The questionnaire thus provided absolute ratings of noise adequacy as well as a comparison of crew assessment of the noise and their reaction to other factors. The questionnaire is discussed more fully in reference 2.

The day after leaving the chamber, an extensive debriefing was conducted. Approximately 15 minutes of this debriefing were spent on noise. The approach was to ask general and nondirective questions to facilitate spontaneous crew comments.

The second day after leaving the chamber, the crew members were given noise questionnaires. These were used to obtain detailed and specific information about the noise levels, behavioral effects of the noise, crew judgments of the adequacy of the noise levels for future long-duration missions, and reactions to the behavioral acoustics test battery.

RESULTS

Behavioral Test Data

Examination of the audiometric data suggested that they be summarized in six categories: loss (two crew members) versus no loss (two crew members) and low (500 and 1,000 Hz), medium (2,000 and 3,000 Hz), and high (4,000 and 6,000 Hz) frequencies. Figure 1 shows the audiometric data grouped in these categories. Average levels for loss and no-loss groups were somewhat different because one crew member in the loss group showed hearing loss at a consistently higher level than the other three crew members. The curves for loss and no-loss groups were therefore adjusted, equating pre-test levels to facilitate comparisons.

The no-loss group showed no significant hearing loss during the 90-day test, but did show pre-post differences. The loss group showed a nearly linear increase in loss over the 90 days, but their pre-post changes are almost identical with the no-loss group.

Figure 2 shows typical results for the speech comprehension tests. No trends were noted here, indicating that no degradation in ability to comprehend speech occurred during the test.

Figure 3 displays typical data for the acceptability tests. Three of the crew members showed no significant changes. The fourth member found the simulator noise less acceptable as the test progressed. The further decrease in acceptability after the test was not expected but seems reasonable. It would suggest that the crew member disliked having to listen again to the unpleasant noise. The crew member who showed this sensitivity also reported the most dislike of the cabin ambient levels.

Acceptability matching and speech comprehension test results were of only minor importance. Although one subject showed sensitization to the cabin noises, he had also reported dislike of the noise environment during his subjective evaluations. There were indications of communication difficulties during the 90-day test, but the absolute level of difficulty in real communications could not be derived from the tests used.

Audiometric results were difficult to interpret. Week-to-week variability was large enough to obscure important changes in individual data, requiring consolidation of the data into six summary groups. Since the no-loss group showed the same change from pre-test to post-test as the loss group, it is probable that these changes are at least partly artifacts and that no real pre-post changes occurred (i.e., the two subjects showing changes returned to normal by the first post-test). The second post-test showed even more loss than the first, and this strongly suggests that the changes result from decreases in motivation. Of all the behavioral acoustics tests administered, the audiometric tests should be used during future tests and missions, since they are relatively simple to implement, can be self-administered, and yielded the only important changes. However, sources of week-to-week audiometric variation should be studied in greater detail. Two possible causes are intermittent noise and earphone placement. The problem of assessing or minimizing the effects of change in motivation will require additional study. Many audiometric techniques, especially tracking methods as used in these tests, have been developed or adapted to minimize gross problems such as malingering. However, with a cooperative individual such as an astronaut, the problem is a much more subtle one of concentration and degree of involvement with the task. Furthermore, the amount of change of interest for these studies is much smaller than when screening for large hearing losses.

Subjective Data

Data from the habitability questionnaire, post-test questionnaire, and debriefing were very similar and give high confidence in the results. The crew members found the 64-dB(A) crew quarters noise quite reasonable, but

disliked the 77-dB(A) equipment area, even though only a portion of their time was spent in the equipment area. There was agreement that the 77-dB(A) equipment room ambient noise would be unacceptable for living quarters. There were complaints about intermittent noises, such as pumps cycling on and off and crew activities including talking. These intermittent noises mainly interfered with sleeping. There were comments on some communication difficulties evidenced by the need to repeat statements during both conversations among crew members and communications with the simulator control room.

Crew evaluation of the behavioral acoustics tests indicated a concern for the length and repetitious nature of the tests and for the distracting intermittent noises. The audiometric test was liked best and the acceptability test least. Subjects were aware of the week-to-week repetition of the word lists for the speech comprehension tests and believed that this might have influenced their answers somewhat.

CONCLUSIONS

The following conclusions were reached regarding the effects of simulator ambient noise on the crew members:

- Two of the four crew members experienced some hearing loss. Recovery apparently occurred during the post-test period. Random variation between weeks prevented a detailed description of hearing patterns.
- Only one crew member showed a trend of acceptability change toward increased sensitization or annoyance with the simulator noise levels. This crew member showed even more dislike for the cabin noise during post-tests and reported the most subjective dissatisfaction with the cabin noise. This result suggests that selection of crew members for long-duration missions should consider this factor.
- The speech comprehension tests showed no consistent significant effects.
- The attained levels of NCA 55 and 70 [64 and 77 dB(A)] were close to minimum-desired and maximum-tolerable noise levels. The difference between NCA 55 and 70 represents a clear and important change in acceptability.
- Intermittent noises were a meaningful source of dissatisfaction, especially when trying to sleep.

Based on these conclusions and an analysis of the adequacy of the testing program, the following major recommendations are offered:

- Audiometric monitoring during extended simulations or missions would be desirable.
- Efforts should be made to increase the consistency of audiometric data.
- Future acoustic tests could be limited to audiometry without losing much information.
- The NCA 55 and 70 attained levels appear to be reasonable for future minimum standards.
- Additional reduction of the equipment area noise by at least 5 dB or reduction of time required in the equipment area would be desirable but probably not critical.
- An effort should be made to reduce intermittent noises, such as pump noise, door noise, and talking, especially in the sleeping quarters, or to eliminate their intrusion upon sleeping crew members.

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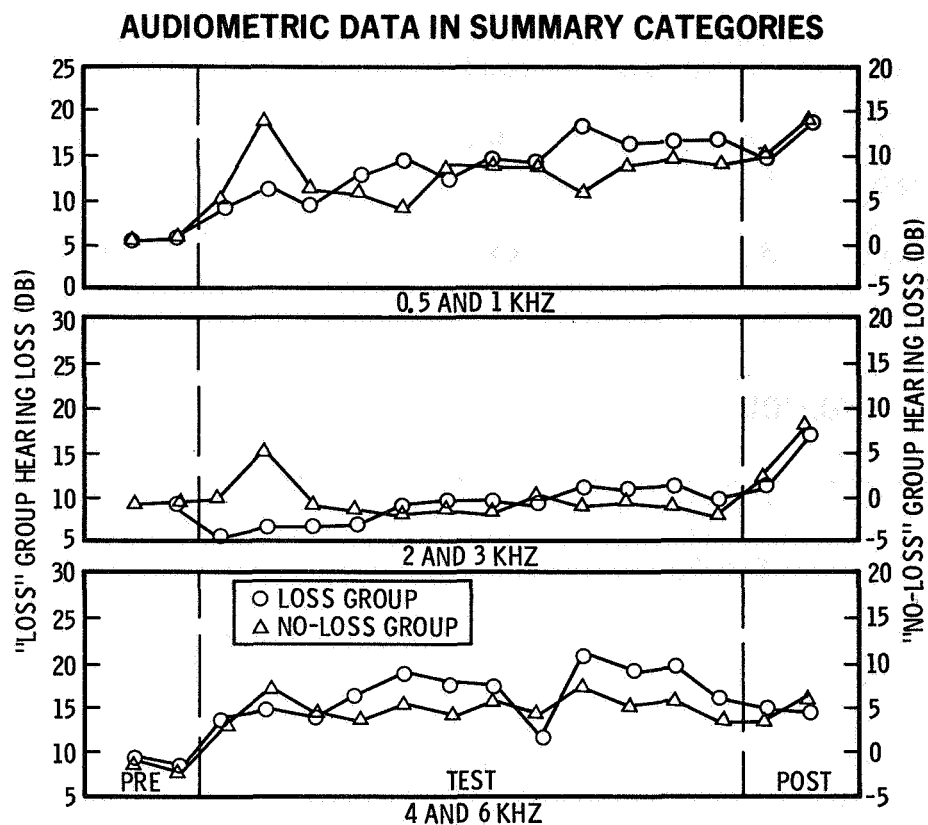


Figure 1

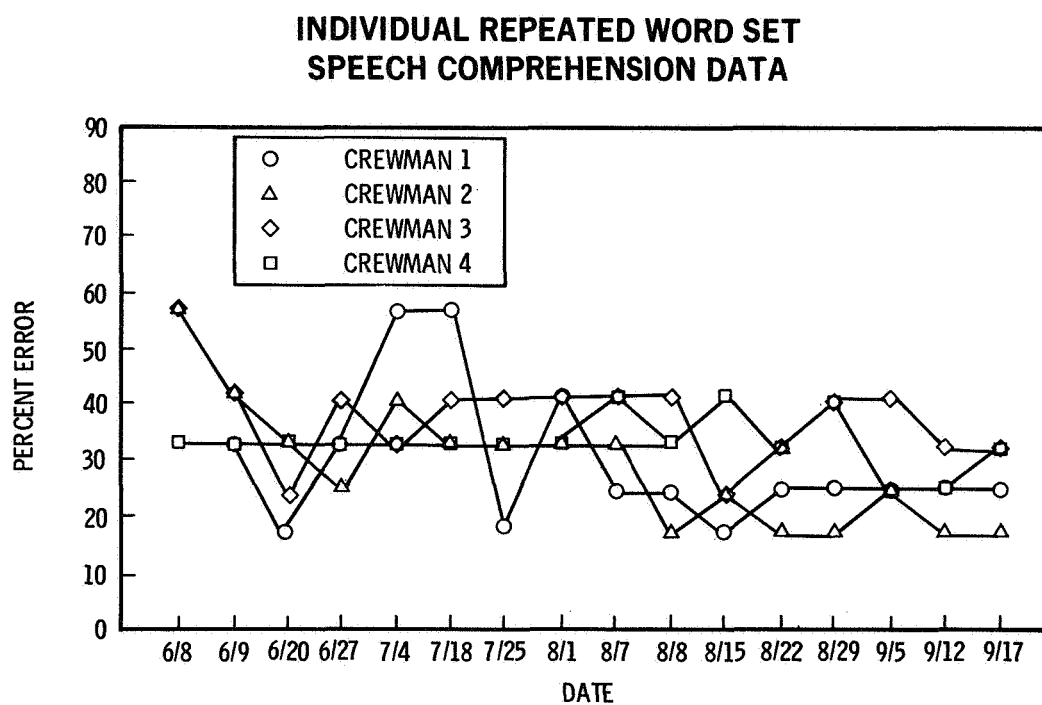


Figure 2

INDIVIDUAL LOW AMBIENT ACCEPTABILITY DATA

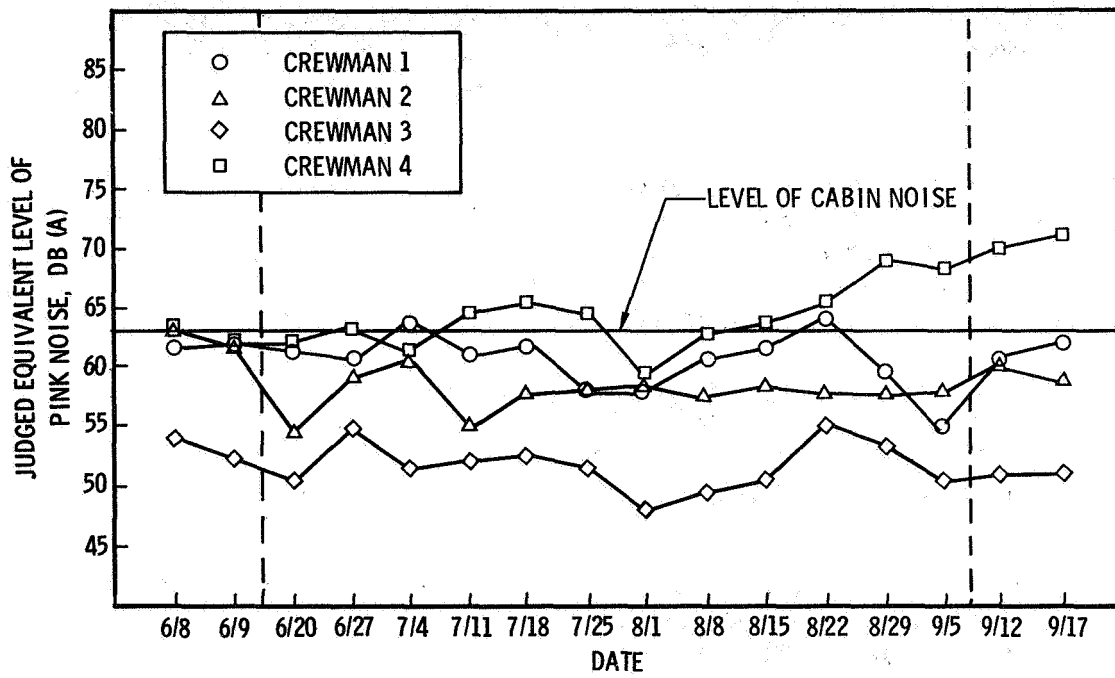


Figure 3

EEG MONITORING/SLEEP STUDIES

By R. D. Joseph, W. B. Martin, and S. S. Viglione

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SUMMARY

The 90-day test program provided for the acquisition and analysis of EEG and EOG recordings taken from 39 nights of sleep divided between two subjects. Approximately 350 hours of data were acquired and analyzed.

Equipment required for collecting, monitoring, and recording of the EEG and EOG was selected. All items to be maintained within the Space Station Simulator (SSS) were screened for toxicity, flammability, and electric shock hazard in compliance with the NASA safety program.

A data collection and monitoring station consisting of telemetry receivers, tape recorder, and chart recorder was installed in the vicinity of the simulator. The station was located to minimize interference with operation of the support facilities. A reliable physiological telemetry link between the test crew and the recording station was established.

An automatic scoring system was designed for each of the two subjects participating in the sleep studies. Six classifications are provided: awake, rapid eye movement (REM), and stages 1 through 4, as defined by the Association for the Psychophysiological Study of Sleep (APSS).¹ In addition, movements and artifacts were also detected.

The crewmen were indoctrinated in the role of the EEG and EOG recordings and trained in the methodology of preparing themselves for the EEG and EOG recordings. The importance of proper electrode attachment technique and correct electrode placement was stressed, since the quality of the EEG data is dependent upon proper homologous positioning and achievement of minimum resistance from the scalp to scalp positions. An electrode resistance tester was included for this function. The crewmen were also trained in the use of the telemetry and the scheduling of the recording sessions.

Recording during the 90-day manned test was in accordance with the protocol established in the data collection plan. A trained technician initiated and monitored the recording sequence, maintained a data collection log, and noted unusual circumstances. He also monitored (from outside the SSS) the crew's preparation efforts and noted the effectiveness of electrode application.

The sleep scoring system, developed and validated on baseline data, was applied to the sleep recordings collected during the 90-day test. In addition to detailed printout of sleep stage classifications, the following is also provided for each overnight record.

- A. Graphic representation of sleep stage occurrence (sleep print).
- B. Duration of each major sleep stage period and summary of total amount of time spent in each sleep stage, ratio of time spent in various stages, number of transitions between stages, number of movements, In all, forty five (45) parameters were extracted from the daily sleep information for each subject to attempt to obtain a measure of the "quality" of the sleep. These parameters and the results are discussed further in the text.
- C. Plots of energy within specific bandwidths (e.g., delta, sigma) as a function of time.

INSTRUMENTATION

Two biotelemetry transmitters were placed in the chamber. They provide a pulse width-frequency modulated signal at approximately 88 MHz containing four multiplexed channels of data. Only one transmitter was used; the other was kept in reserve. A signal source in the chamber provided an 82-microvolt, 5-Hz square wave for calibration. The calibrator box contains a circuit which measures the resistance of each pair of electrodes after application.

The receiving antenna and lead wire were an insulated piece of wire strung along the chamber wall dropped from the ceiling. Outside the chamber this wire mated with a shielded wire which led to the data recording station. The demodulated data (two channels of EEG and two of EOG) were recorded on tape and simultaneously displayed on a chart recorder. Three of the recorded channels were read back immediately and also displayed on the chart recorder to ensure proper operation of the recording system. A time code generator, synchronized with one in the control room, produced IRIG B signals which were also recorded on tape and a binary output for display on the chart recorder.

Placement of EEG and EOG electrodes followed the recommendations pertinent to sleep research and published by the National Institute of Health.¹

A log book was maintained for recording data pertinent to the sleep recordings, particularly regarding artifacts, comments by the crewman concerning attitude, subjective evaluation of his sleep, naps taken during the day, and other pertinent information.

SELECTION AND TRAINING OF PARTICIPANTS

All four crewmen participated in a training session on May 27. Topics discussed included the collection of EEG and EOG data as information pertinent to sleep stage identification, sleep research in general, objectives of this project in particular, operation of the telemetry system, application of electrodes, and also typical checkout and calibration problems. Each crewman received a pamphlet listing materials to be used, procedures for operation of telemetry, electrode application, and electrode evaluation. Each crewman had an opportunity to apply electrodes to the other, to learn the placement of electrodes, operate and calibrate the telemetry, and observe the resulting EEG during various conditions such as eyes open, eyes closed, alertness, and resting. All participants showed significant interest in this study and were able to obtain a good, clean recording.

Two crewmen were selected on the basis of EEG data recorded during this session, the criterion being a relatively high level of alpha activity. A board-certified neurologist (Dr. Barbara Jensen, Newport Beach, California) compared this remotely obtained EEG with the clinical EEG done in her laboratory and concurred with the selection.

BASELINE RECORDING SESSION

For the purpose of obtaining baseline sleep information from the selected participants, the two selected crewmen were instrumented for recording on June 7 and 8 between 2300 and 0630. Both crewmen slept in hospital beds (adjustable) placed in a room at Astropower Laboratory. Each applied electrodes to the other (under supervision) and tested performance of the equipment; this was done in a separate room, removed from their sleeping quarters.

The Pattern Recognition Group personnel monitored and documented the recording sessions. Two outside consultants (specializing in sleep research) (Drs. L. Johnson and P. Naitoh, San Diego College) participated in the first night's recording, made final decisions on electrode placement, evaluated the first hour of recording, and the next day participated in initial sleep scoring (using the manual-visual method).

DATA COLLECTION

Three periods of data collection were scheduled: days 1 through 10; days 42 through 46; and days 85 through 89.

Data collection was begun on the first day at 2300, the time of the first scheduled sleeping period for the crewman on the unaltered sleep cycle. For various reasons, no recordings were made of the other crewman until his third scheduled sleeping period. Data were taken during 10 consecutive nights for the former and 9 consecutive nights for the latter.

A procedure was established for checkout and calibration of the telemetry, installation of fresh batteries, application of electrodes, and communication between crewmen and monitoring personnel.

Availability and cost of chart paper made it possible to record only the first two sessions from each subject at a speed which permits manual scoring of sleep. For the rest of the sessions the paper was run just fast enough to check the quality of recording and read the time code for later elimination of artifacts and interference from the computer-aided analysis.

Problems encountered included some unavoidable interference from various electrical appliances around the chamber and occasional loss of signal due to a sleeper either rolling on top of the telemetry or knocking off an electrode. It has been determined that better than 90 percent of the data collected was usable for the subsequent data analysis.

DATA ANALYSIS

The analysis of the recorded data involves several processing operations. The basic analysis is the automatic scoring of each 30-sec epoch of the recorded EEG/EOG data into a sleep stage (or a movement or artifact categorization). This is accomplished using a pattern recognition design procedure. A functional block of the processing and analysis is shown in fig. 1. The analog EEG data are sampled at 68.5 Hz and quantized to 10 bits. The resulting digital data are then processed by an FFT² algorithm to extract the frequency information from 0 to 34 Hz in 1-Hz increments for each 30 sec. These 34 parameters, representing the amplitude squared values ($\mu\text{V}^2/\text{Hz}$) of the frequency constituents in the EEG, provide the input to the pattern recognition system for subsequent classification.

The design of the classification system involves a pattern recognition learning algorithm³ which classifies each 30-sec epoch into one of six sleep stage categories (stages awake, REM, 1, 2, 3, and 4). As illustrated in fig. 1, four separate classification systems are designed, using the baseline data as the training sample, to perform dichotomous classifications at each node (labeled 1 through 4 in fig. 1). A decision tree structure is thus evolved. At node 1 the dichotomization involves separating stages 3 and 4 from all others. Node 2 separates stage 3 from stage 4. Node 3 provides the identification of the awake state and node 4 separates stage 2 from stages 1 and REM.

In addition, the frequency information and the raw digital data are also processed in a REM detection and logic operation to detect the presence of rapid eye movements, gross body movements, and contaminating noise and spurious artifacts. The REM detector uses the total power in the EEG trace, the total power in the opposed waves in the EOG and the sharpness of these opposed waves to detect rapid eye movement. The body movement and artifact detection is based on a double thresholding of the power contained in the higher frequencies. If the 30-sec interval contains sufficient energy in the high frequencies to exceed the upper threshold, or sufficient energy in the ratio of the upper frequencies to the total energy to exceed the lower threshold, then an artifact indication is noted. If the energy is concentrated in very low frequencies (0 to 1 Hz) and is of large magnitude, then a body movement indication is provided.

The corresponding output from this REM detection and logic operation is used to supplement or override the classification of the decision tree. A movement detection will override all classifications other than stages 3 and 4. A REM detection will override the stage 1 classification, and a stage 2 classification if that epoch is preceded by a movement; and finally the artifact detection will override all decision tree classifications and cause the last epoch classification to be carried through until the artifact is over. Fig. 2 is an example of the computer printout illustrating the operation of the automatic scoring system.

The output from the scoring system is then processed by a computer program from which the sleep print is generated. Four adjacent 30-sec classification outputs are averaged and a sleep stage noted for that 2-minute interval. Each 2-minute interval is plotted to provide a ready display of the subject's sleep over the entire sleep period. In addition, the quantities used to evaluate the quality of the subject's sleep are also computed. These 45 parameters include length of time in each stage, total sleep time, total awake time, number of movements, number of sleep stage transitions, etc. (see fig. 3).

Finally a statistical summary of each of 43 parameters is computed for all of the sleep periods in the cabin for each crewman. These are provided in both tabular and graphical form to display trends and inconsistencies in

sleep behavior. The entire operation, including sleep scoring and statistical summary and plotting, takes about 3 to 3 1/2 hours for each 9 to 10 hour sleep period using the XDS 930 computer.

COMPUTER PROCESSING RESULTS

The scoring of the sleep records is the fundamental step in arriving at an assessment of sleep quality. However the output of the scoring systems, a stage categorization for each 30-sec epoch of sleep, is still too extensive to be easily absorbed. Further data reduction is in order.

Sleep researchers rely on certain accepted parameters extracted from the scored data as well as sleep prints and plots of the delta activity in evaluating sleep. For the most part, these parameters deal with the rhythmic nature of the sleep and the relative and absolute quantities of the various sleep activities. Most parameters are not related to the very fine structure of sleep.

In the course of extracting these parameters, the first step is to obtain those which do use fine structure—namely, those dealing with movement or arousal episodes. Then the 30-sec data are combined to provide 2-minute scoring epochs. This tends to minimize chatter in the scoring as the sleeper is near the boundary between sleep stages. Such smoothing is provided subjectively in the hand scoring of sleep records. The sleep prints are plotted directly from these 2-minute data, and they form the basis for the great majority of the sleep parameters.

The computer provides a listing of the parameters extracted for each sleep period. The first 43 items (fig. 3) are the primary output. Histograms of the duration of various types of sleep episodes (item 44, Fig. 3) are given, as is a table of the REM-to-REM intervals (item 45, fig. 3). This listing is immediately followed by a graphic representation of the sleep stages, the sleep print.

The sleep print of fig. 4 is not taken from one of the crewmen. Rather, it is descriptive of EEG changes observable during a typical night. There is the regular transition through the stages, reaching stage 4 within an hour. The stage 4 episode lasts for perhaps half an hour and leads to the first REM period. A second stage 4 episode may or may not occur; but if it did, it would be in the second slow wave episode near the 2-hour mark. The plot of the delta activity above the sleep print provides a ready reference for slow wave sleep. The remainder of the night is spent in a regular REM-stage 2 cycle, with perhaps a minor amount of stage 3. Notice the relatively few stage changes.

Fig. 5 represents perhaps the closest approach, in the nights monitored, to the prototype above. There are many more stage changes than one would expect. Indeed this is one of the more striking features of chamber sleep—that there are 2 to 4 times as many stage changes as normally encountered. Note also the limited amount of slow wave sleep.

With these sleep prints, relative levels of delta activity are also plotted. The rigid criteria defined for stages 2, 3, and 4 provide a coarse quantization of what appears to be a somewhat continuous increase and decrease in low frequency activity (0.5 to 2 Hz). To highlight this waxing and waning of delta activity, a time history of activity in the delta band is plotted, based also upon 2-minute epochs. These plots tend to reveal more clearly the rhythmic nature of the sleep patterns which may have been obscured by the sleep stage quantifications. These also show the rhythmicity of sleep, delta being minimal during REM and stage 1 and building up to a maximum in stage 4.

The sleep parameters are tabulated in a summary chart for each of the participating crewmen (figs. 6 and 7). The parameters are subdivided by types. First comes the grossest—total bed time, sleep time, and wake time. Next is a breakdown by sleep classes and combinations of sleep classes. The time to onset of each stage is followed by the average duration of certain episodes. Then most of these are converted to percentages. Finally, the number of episodes of various types and the number of stage changes are given. Results for all nights of the sleep study are shown on these charts as well as the average value for each parameter.

Probably the most striking item on these charts is the lack of slow wave sleep. One crewman averaged 30 minutes per night for stages 3 and 4 combined and the other averaged only 5 minutes per night. This result is not out of keeping with results of other confinement studies, for example Jay Shurley's analysis of the South Polar Expedition.

To facilitate the search for trends, bar charts are produced for each of the parameters. Fig. 8 shows total waking time. A downward trend is exhibited during the first 5 days showing an adaptation to the new environment. There is then a rising trend, showing up most dramatically during the last 5-day recording period as the anticipation of the end of the 90-day run mounted.

CONCLUSIONS

Using the biotelemetry system and with a minimum of training of the crewmen, it has been demonstrated that consistent and reliable monitoring of the physiology of subjects in confinement can be performed. Little crew discomfort was noted although some consideration should be given to easing the electrode application task. A skull cap or other head covering with pre-prepared electrodes (such as that developed by Dr. J. Frost, Baylor University for NASA MSC) should be considered for subsequent experiments.

A methodology has been developed which provides for the rapid processing of the EEG and related physiologic parameters. The automatic pattern recognition sleep scoring system has demonstrated sleep stage classification results consistent with those of a human scorer, without the inconsistencies of the subjective scoring and eliminating the tedium of manual scoring. A statistical summary of sleep parameters is readily computed, and trends in sleep activities are displayed for crew evaluation.

The analyzed data demonstrate a trend toward more sleep in the first 10 days of confinement and less sleep later on, although total bed time remains about the same and both crewmen appear to have obtained adequate sleep. This trend is unsupported by crew reports of sleep time.

Total wake time tapered off during the first 10 days reflecting some adaptation to the chamber. The amount of wake time before sleep showed a defined increase from the beginning to the middle to the end of the 90-day run, and wake time in bed after sleep also shows a definite increase with time. These findings tend to support those of Antarctic groups.

The sleep behavior of the crewmen monitored during this experiment appeared to deviate little during the course of the 90-day run. It was noted that both crewmen tended to have little slow wave sleep activity (stages 3 and 4), averaging 30 minutes per night for one crewman and a miniscule 5 minutes per night for the other.

The most interesting psychological changes in the crewmen occurred between days 60 and 70 (see paper no. 29 by J. S. Seeman and M. V. McLean and paper no. 35 by M. M. Okanes, W. R. Feeney, and J. S. Seeman). It would have been impossible to forecast this, and it is unfortunate that the limited scope of the sleep monitoring did not include this time period.

We wish to express our deep appreciation of the outstanding job accomplished by the two participating crewmen. With less than 2 hours of training, they were able to provide a virtually flawless performance in the exacting task of electrode application. The success of this experiment can be largely attributed to their cooperative attitude throughout.

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AUTOMATIC SLEEP SCORING AND SLEEP PERFORMANCE ANALYSIS

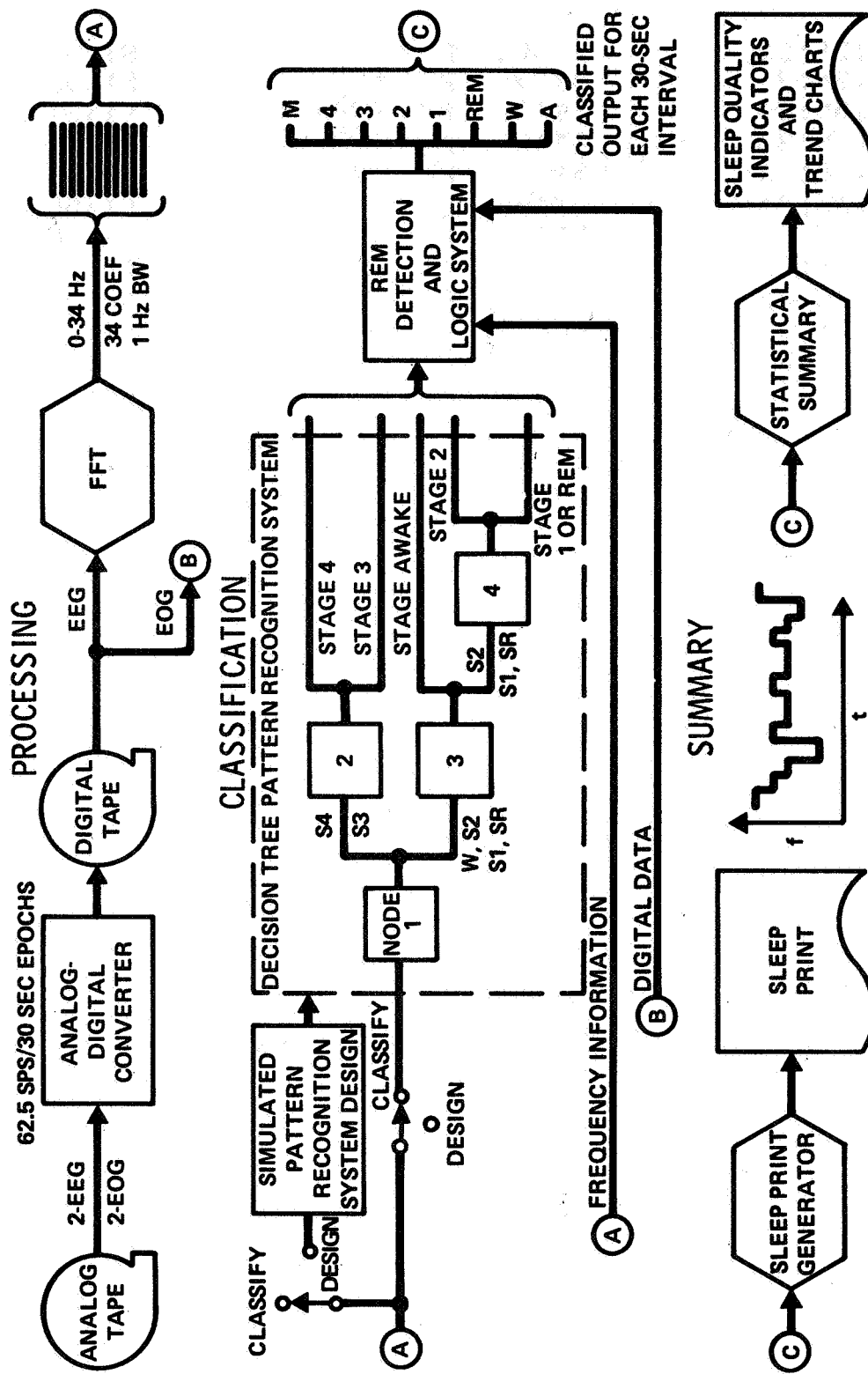


Figure 1

COMPUTER PRINTOUT -- AUTOMATIC SLEEP SCORING

03:34:00	STAGE	2	STAGE	2
03:34:30	STAGE	2	STAGE	2
03:35:00	STAGE	2	STAGE	2
03:35:30	STAGE	2	STAGE	2
03:36:00	STAGE	2	STAGE	2
03:36:30	STAGE	2	STAGE	2
03:37:00	STAGE	2	ARTIFACT	
03:37:30	STAGE	2	ARTIFACT	
03:38:00	STAGE	2	STAGE	2
03:38:30	STAGE	2	STAGE	2
03:39:00	AWAKE		ARTIFACT	
03:39:30	STAGE	2	ARTIFACT	
03:40:00	STAGE	2	STAGE	2
03:40:30	STAGE	2	STAGE	2
03:41:00	STAGE	2	STAGE	2
03:41:30	STAGE	2	STAGE	2
03:42:00	STAGE	2	STAGE	2
03:42:30	STAGE	2	STAGE	2
03:43:00	STAGE	2	STAGE	2
03:43:30	AWAKE		STAGE	2
03:44:00	REM		TRANSIT.	
03:44:30	REM	REM	REM	
03:45:00	REM	REM	REM	
03:45:30	REM	ARTIFACT	ARTIFACT	
03:46:00	REM	ARTIFACT	ARTIFACT	
03:46:30	REM	ARTIFACT	ARTIFACT	
03:47:00	REM	ARTIFACT	ARTIFACT	
03:47:30	REM	ARTIFACT	ARTIFACT	
03:48:00	REM	ARTIFACT	ARTIFACT	
03:48:30	REM	REM	ARTIFACT	
03:49:00	REM		ARTIFACT	
03:49:30	REM	REM	ARTIFACT	
03:50:00	REM	ARTIFACT	MOVEMENT	
03:50:30	REM		MOVEMENT	
03:51:00	REM		REM	
03:51:30	REM		REM	
03:52:00	REM		REM	
03:52:30	REM		REM	
03:53:00	REM		REM	
03:53:30	REM	REM	REM	
03:54:00	REM	REM	REM	
03:54:30	REM		REM	
03:55:00	REM	REM	REM	

Figure 2

TERRY DONLEN 30 DAY RUN
 TEST NO. 3 ANALOG TAPE NO. 3
 RECORDED AFTERNOON JUNE 16, 1970
 DIGITIZED JULY 7, 1970

[illegible]

Figure 3

DELTA ACTIVITY (0.2 TO 2 Hz) AND SLEEP STAGES VS SLEEP TIME

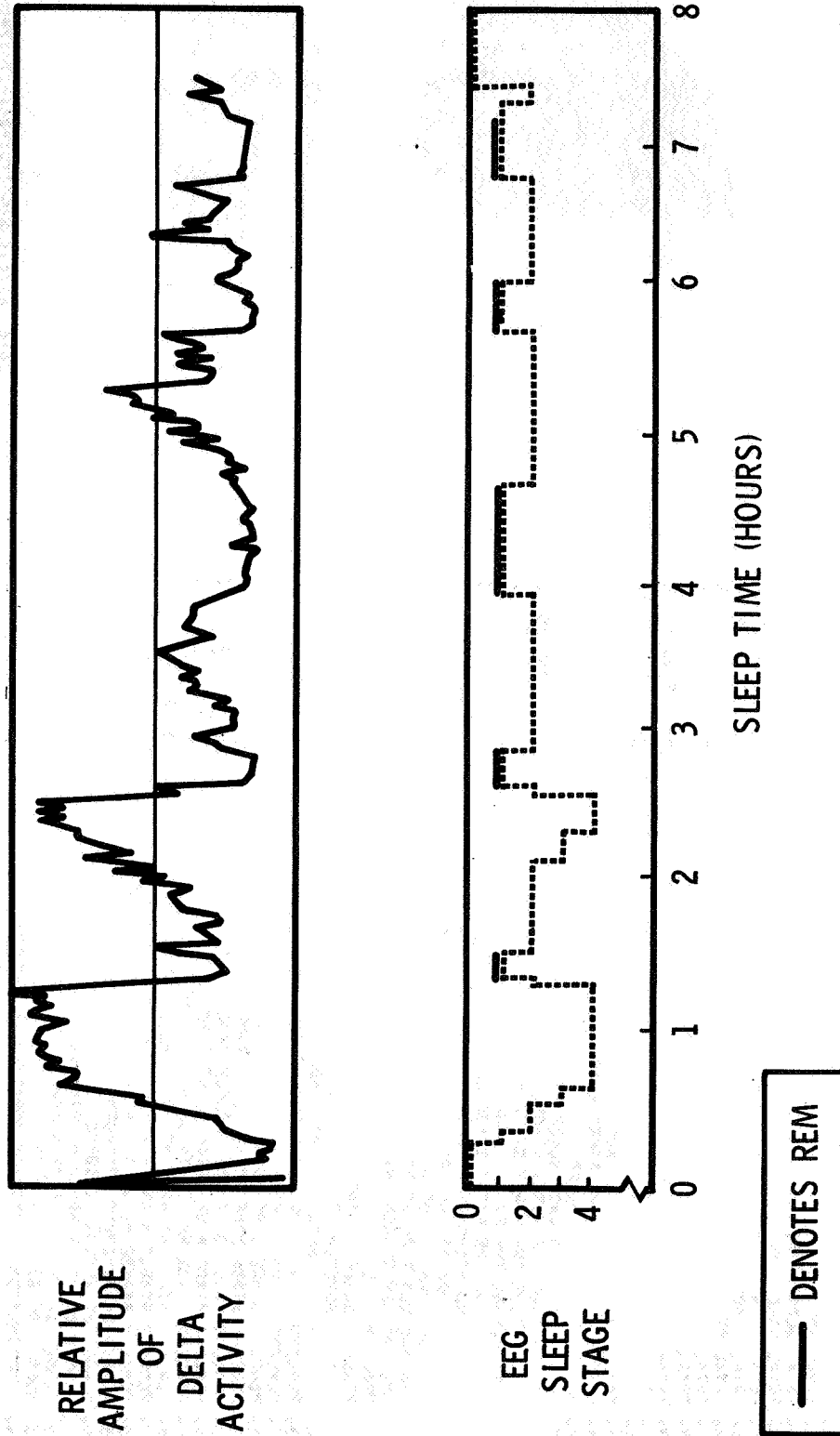


Figure 4

SLEEP PRINT -- UNALTERED SLEEP CYCLE

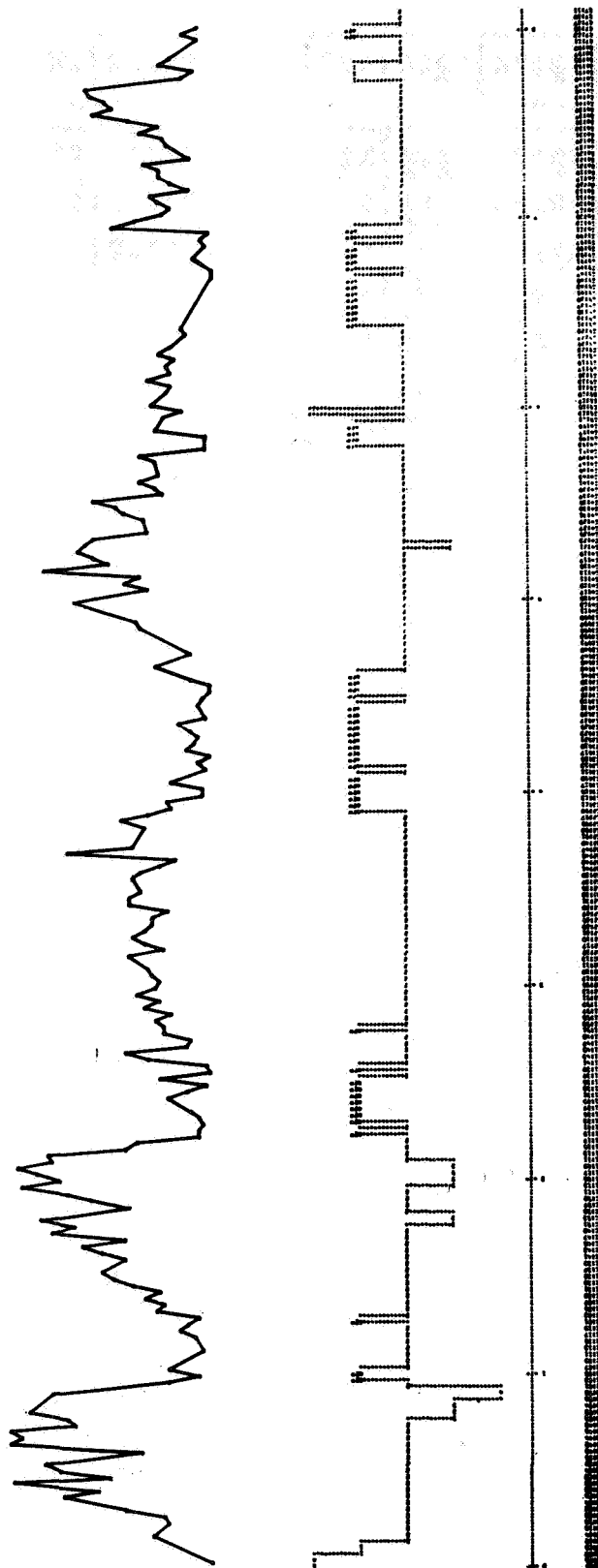


Figure 5

20-DAY SUMMARY CHART -- SLEEP PARAMETERS, UNALTERED SLEEP CYCLE

UNALTERED SLEEP CYCLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVE
TOTAL BED TIME.....	520	502	504	376	488	470	530	468	472	468	580	578	508	388	488	504	380	482	464	544	485
TOTAL SLEEP TIME.....	444	484	464	384	482	466	486	446	448	452	468	544	416	342	446	428	274	396	410	430	433
TOTAL WAKE TIME.....	74	48	38	22	6	4	44	22	24	16	112	34	92	46	42	68	106	56	54	134	52
TOTAL STAGE 1.....	4	22	14	4	10	10	8	2	12	0	4	8	4	6	4	24	8	22	2	10	9
TOTAL STAGE 2.....	296	328	316	282	342	344	330	328	316	326	324	378	292	250	328	240	174	242	330	312	303
TOTAL STAGE 3.....	30	14	28	22	20	18	34	14	44	24	30	36	34	30	26	38	30	54	10	22	28
TOTAL STAGE 4.....	8	0	6	4	4	6	2	2	0	2	0	0	2	0	2	2	0	6	0	0	2
TOTAL REM.....	108	90	102	70	106	88	108	98	76	100	110	122	80	58	84	124	62	72	68	86	91
TOTAL MOVEMENT TIME.....	19	4	2	0	1	3	2	8	9	3	3	3	5	5	3	59	15	2	0	2	7
TOTAL NON-REM.....	338	364	364	284	376	378	378	348	372	352	358	422	336	284	342	304	212	324	342	344	342
TOTAL OF STAGES 3 AND 4.....	38	14	34	28	24	24	36	18	44	26	30	36	36	30	28	40	30	60	10	22	30
TOTAL OF STAGES 2, 3, AND 4.....	334	342	350	280	366	368	370	346	360	352	354	414	328	280	356	280	204	302	340	334	333
WAKE TIME BEFORE FIRST STAGE 2.....	10	10	2	8	4	2	10	0	8	12	10	8	68	8	22	38	46	6	18	68	18
WAKE TIME DURING SLEEP.....	52	36	36	6	2	9	18	22	4	0	102	14	2	4	8	0	2	50	6	66	22
WAKE TIME AFTER SLEEP.....	12	2	0	8	0	2	16	0	12	4	0	12	22	34	12	30	58	0	30	0	13
TIME BEFORE FIRST STAGE 2.....	10	10	2	8	8	2	10	0	10	12	12	8	68	10	22	40	48	10	18	70	19
TIME BEFORE FIRST STAGE 3.....	48	84	114	88	46	238	48	56	42	52	30	36	118	28	56	58	68	72	46	108	170
TIME BEFORE FIRST STAGE 4.....	44	116	26	52	36	58	74	54	54	54	74	188	60	60	60	48	84	84	84	84	70
TIME BEFORE FIRST REM.....	48	78	60	38	58	50	144	86	56	70	74	76	128	88	86	90	104	106	70	134	83
AVERAGE DURATION OF MOVEMENTS.....	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
AVERAGE DURATION OF AROUSALS.....	5	4	5	2	1	2	3	2	8	2	9	3	5	5	3	6	18	11	3	7	5
AVERAGE DURATION OF NON-REM.....	89	44	43	37	52	46	39	57	45	37	41	48	58	44	56	32	44	74	41	58	48
AVERAGE DURATION OF REM.....	19	10	11	11	21	15	16	25	13	14	13	18	18	13	14	16	12	14	10	14	15
AVERAGE REM-TO-REM INTERVAL.....	84	51	53	54	53	64	46	53	58	48	54	69	66	53	46	44	35	83	49	56	61
PCT. WAKE OF BED TIME.....	14	10	8	6	1	9	92	95	95	97	81	94	82	88	91	85	72	88	88	76	89
PCT. SLEEP OF BED TIME.....	84	90	92	94	99	91	8	5	3	1	1	1	1	1	1	12	4	0	0	1	1
PCT. MOVEMENT TIME OF BED TIME.....	4	1	0	0	0	1	0	2	2	1	1	1	1	1	1	1	1	1	1	1	1
PCT. OF WAKE BEFORE FIRST 2.....	14	21	8	36	47	80	23	0	33	75	9	24	74	17	52	56	43	11	33	51	35
PCT. OF WAKE DURING SLEEP.....	70	78	98	87	33	0	41	100	17	0	91	41	2	9	19	0	2	89	11	49	39
PCT. OF WAKE AFTER SLEEP.....	16	4	0	34	0	80	36	0	50	25	0	35	24	74	29	44	98	0	56	0	27
PCT. STAGE 1 OF SLEEP.....	1	5	3	1	2	2	2	0	3	0	1	1	2	1	1	6	3	6	0	2	2
PCT. STAGE 2 OF SLEEP.....	64	78	68	71	71	74	49	74	71	72	69	69	70	73	74	96	64	61	80	73	70
PCT. STAGE 3 OF SLEEP.....	7	3	4	4	4	4	7	4	10	5	6	7	8	9	6	9	11	14	2	5	7
PCT. STAGE 4 OF SLEEP.....	2	0	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
PCT. REM OF SLEEP.....	24	20	22	20	22	19	22	22	17	22	24	22	19	17	19	29	23	18	17	20	21
PCT. NON-REM OF SLEEP.....	76	80	78	80	78	81	78	78	83	78	76	78	81	83	81	71	77	82	83	80	79
PCT. STAGES 3 AND 4 OF SLEEP.....	3	3	7	8	5	5	7	4	10	6	4	7	9	9	6	9	11	15	2	5	7
PCT. STAGES 2,3 AND 4 OF SLEEP.....	75	75	75	79	76	79	76	78	80	78	76	76	79	82	80	65	74	76	83	78	77
NUMBER OF MOVEMENT EPISODES.....	24	7	3	0	1	5	3	12	16	5	4	6	9	9	4	67	22	4	0	3	11
NUMBER OF AROUSAL EPISODES.....	14	15	10	10	11	8	15	18	4	2	13	15	7	8	8	12	4	6	15	11	10
NUMBER OF NON-REM EPISODES.....	7	5	5	8	7	8	10	6	8	9	11	9	7	7	7	11	7	8	9	8	8
NUMBER OF REM EPISODES.....	6	9	9	7	6	7	9	5	8	9	10	8	6	6	7	10	6	8	9	7	7
NUMBER OF STAGE CHANGES.....	30	37	51	34	41	36	57	40	50	48	52	46	35	34	38	56	34	48	39	34	42

Figure 6

19-DAY SUMMARY CHART -- SLEEP PARAMETERS, ALTERED SLEEP CYCLE

ALTERED SLEEP CYCLE	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg
TOTAL BED TIME.....	470	434	400	344	446	398	428	516	512	348	566	460	530	478	520	520	520	520	520	520	520	520	520	520	520	520	520	520	520	520	520
TOTAL SLEEP TIME.....	428	386	366	310	342	354	424	508	470	318	548	432	510	454	494	478	486	498	496	494	494	494	494	494	494	494	494	494	494	494	494
TOTAL WAKE TIME.....	42	48	34	34	104	44	4	8	42	30	16	26	14	24	18	36	28	24	22	18	36	28	24	22	18	36	28	24	22	18	36
TOTAL STAGE 1.....	36	90	32	30	110	84	68	32	68	2	12	38	26	24	16	28	44	54	26	43	16	28	44	54	26	43	16	28	44	54	26
TOTAL STAGE 2.....	312	248	224	204	224	208	176	358	330	248	406	288	352	292	248	380	316	358	344	295	380	316	358	344	295	380	316	358	344	295	380
TOTAL STAGE 3.....	0	0	2	14	2	0	0	10	10	14	6	0	6	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL STAGE 4.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL REM.....	80	48	108	60	6	62	180	108	60	54	124	106	126	96	92	116	124	142	122	95	92	116	124	142	122	95	92	116	124	142	122
TOTAL MOVEMENT TIME.....	1	1	1	1	4	1	1	11	13	1	32	33	32	16	34	58	35	59	11	18	402	362	362	416	374	343	343	343	343	343	343
TOTAL NON-REM.....	348	338	288	280	336	292	244	400	410	264	424	328	384	328	402	362	362	416	374	343	402	362	362	416	374	343	343	343	343	343	343
TOTAL OF STAGES 3 AND 4.....	0	0	2	14	2	0	0	10	10	14	6	0	6	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OF STAGES 2, 3, AND 4.....	312	248	226	220	226	208	176	368	342	262	412	288	352	304	386	334	318	362	348	300	386	334	318	362	348	300	386	334	318	362	348
WAKE TIME BEFORE FIRST STAGE 2.....	10	6	4	4	20	0	0	0	4	0	2	6	14	8	10	6	8	14	14	6	10	6	8	14	14	6	10	6	8	14	14
WAKE TIME DURING SLEEP.....	14	18	6	4	30	22	0	8	38	0	12	0	0	0	20	20	18	18	18	12	20	20	18	18	18	12	20	20	18	18	12
WAKE TIME AFTER SLEEP.....	18	24	24	26	54	22	4	0	0	30	2	20	0	46	0	10	0	0	0	15	0	10	0	0	0	15	0	10	0	0	15
TIME BEFORE FIRST STAGE 2.....	16	10	10	12	38	8	0	8	0	0	4	10	16	22	22	22	24	24	24	13	22	22	24	24	24	13	22	22	24	24	13
TIME BEFORE FIRST STAGE 3.....	-	-	42	32	66	-	-	42	42	42	34	-	38	50	42	-	58	42	36	-	42	-	58	42	36	-	42	-	58	42	36
TIME BEFORE FIRST STAGE 4.....	-	-	-	-	-	-	-	-	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TIME BEFORE FIRST REM.....	58	102	64	68	260	126	244	70	66	58	62	128	80	84	146	110	160	140	76	111	146	110	160	140	76	111	146	110	160	140	76
AVERAGE DURATION OF MOVEMENTS.....	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AVERAGE DURATION OF AROUSALS.....	6	11	4	5	9	7	22	3	5	7	2	6	1	11	2	5	8	4	3	6	2	5	8	4	3	6	2	5	8	4	3
AVERAGE DURATION OF NON-REM.....	62	123	58	69	221	63	117	67	74	72	61	70	66	75	68	78	84	71	68	81	68	78	84	71	68	81	68	78	84	71	68
AVERAGE DURATION OF REM.....	20	33	28	15	5	21	195	23	14	20	16	28	27	27	23	32	15	33	25	32	23	32	15	33	25	32	23	32	15	33	25
AVERAGE REM-TO-REM INTERVAL.....	95	157	100	88	0	78	0	79	81	81	81	91	86	106	82	106	63	100	90	82	82	106	63	100	90	82	82	106	63	100	90
PCT. WAKE OF BED TIME.....	9	11	9	10	23	11	1	2	8	9	3	6	3	11	3	7	5	4	6	7	3	7	5	4	6	7	3	7	5	4	6
PCT. SLEEP OF BED TIME.....	91	89	92	90	77	89	99	98	92	91	97	94	96	89	95	92	93	95	94	92	95	92	93	95	94	92	95	92	93	95	94
PCT. MOVEMENT TIME OF BED TIME.....	0	0	0	0	1	0	0	2	3	0	6	7	6	3	6	11	7	10	2	3	6	11	7	10	2	3	6	11	7	10	2
PCT. OF WAKE BEFORE FIRST STAGE 2.....	24	13	12	12	19	0	0	0	10	0	13	23	100	15	56	17	29	25	44	22	56	17	29	25	44	22	56	17	29	25	44
PCT. OF WAKE DURING SLEEP.....	33	38	18	12	29	50	0	100	90	0	75	0	0	0	44	56	71	75	56	39	44	56	71	75	56	39	44	56	71	75	56
PCT. OF WAKE AFTER SLEEP.....	43	50	71	76	52	50	100	0	0	100	13	77	0	85	0	28	0	0	0	39	0	28	0	0	0	39	0	28	0	0	0
PCT. STAGE 1 OF SLEEP.....	8	23	9	10	32	24	16	6	14	1	2	9	5	6	3	6	9	10	5	10	3	6	9	10	5	10	3	6	9	10	5
PCT. STAGE 2 OF SLEEP.....	73	64	61	66	65	59	42	70	70	78	74	67	69	69	77	70	65	64	69	67	77	70	65	64	69	67	77	70	65	64	69
PCT. STAGE 3 OF SLEEP.....	0	0	1	5	1	0	0	2	2	4	1	0	1	3	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1
PCT. STAGE 4 OF SLEEP.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCT. REM OF SLEEP.....	19	12	30	19	2	18	42	21	13	17	23	25	25	23	19	24	26	25	25	21	19	24	26	25	25	21	19	24	26	25	25
PCT. NON-REM OF SLEEP.....	81	88	70	81	98	82	58	79	87	83	77	75	75	77	81	76	74	75	75	79	81	76	74	75	75	79	81	76	74	75	75
PCT. STAGES 3 AND 4 OF SLEEP.....	0	0	1	5	1	0	0	2	3	4	1	0	1	3	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1
PCT. STAGES 2, 3 AND 4 OF SLEEP.....	73	64	62	71	66	59	42	72	73	82	75	67	70	72	78	70	65	65	70	68	78	70	65	65	70	68	78	70	65	65	70
NUMBER OF MOVEMENT EPISODES.....	2	2	2	2	8	2	1	20	19	1	48	47	38	25	36	66	35	64	14	23	36	66	35	64	14	23	36	66	35	64	14
NUMBER OF AROUSAL EPISODES.....	10	10	11	10	19	17	3	8	14	5	16	7	10	5	16	8	10	19	12	11	16	8	10	19	12	11	16	8	10	19	12
NUMBER OF NON-REM EPISODES.....	6	3	5	4	12	5	2	6	6	4	7	5	6	5	6	5	6	6	6	5	6	5	6	6	6	5	6	5	6	6	5
NUMBER OF REM EPISODES.....	5	2	4	4	1	4	1	5	5	3	7	4	5	4	5	4	5	5	4	5	3	7	4	5	4	5	3	7	4	5	4
NUMBER OF STAGE CHANGES.....	28	24	19	30	35	26	3	36	33	27	34	29	28	26	36	28	29	41	22	28	36	28	29	41	22	28	36	28	29	41	22

Figure 7

TREND PLOT -- TOTAL WAKING TIME

UNALTERED SLEEP CYCLE

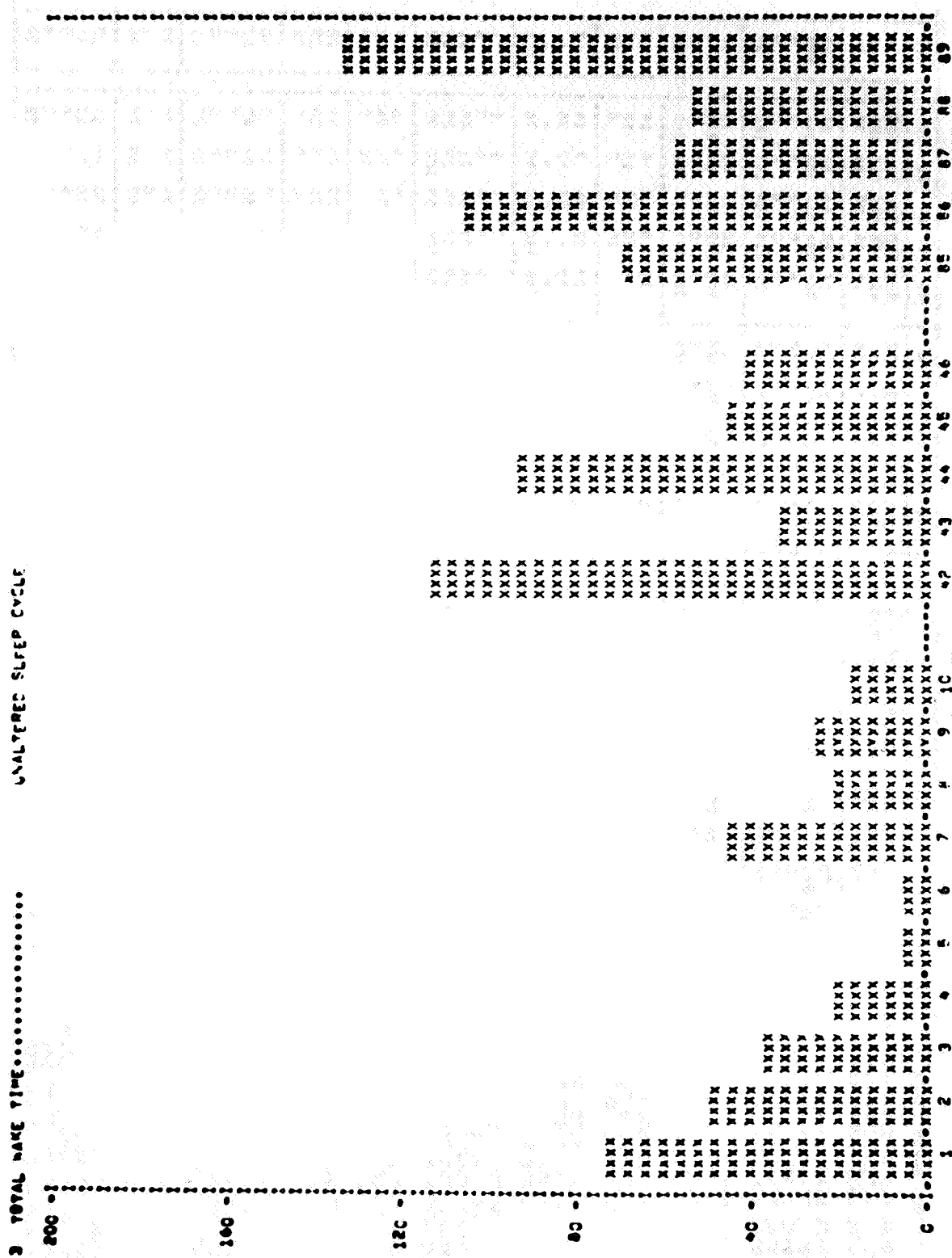


Figure 8

MEDICAL PROGRAM

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SUMMARY

Medical procedures were planned to provide maximum data on crew medical status throughout the test within the constraints of limited pass-outs and onboard crew capabilities. These procedures and associated studies by outside investigators were accomplished without significant problems. Evaluation of the results confirm that the SSS environment was benign medically.

INTRODUCTION

The 90-day manned test medical program was devised primarily to provide near-real-time medical-status information for the crew. Secondary goals involved evaluations of specific stresses encountered during the test, e.g., confinement, altered day-night cycles, low-level CO₂ exposure. Laboratory procedures were constrained by limitations on sample pass-out and by crew capabilities for onboard tests. During the test, the medical director maintained daily records of medical procedure results, which allowed, on several occasions, improvisation of additional tests and, once, directions for medical treatment of a potentially dangerous bacterial finding. Medical operations were gratifyingly smooth with contract physicians on duty for the duration of the test. No medical emergencies were encountered.

MEDICAL PROCEDURES

The medical procedures planned for the operational 90-day manned test of a regenerative life support system were as follows:

Blood biochemistry

Venous electrolytes (NA, K, CA, CL, HCO₃, PO₄)

Venous P_{CO2}, pH, erythrocyte electrolytes (SMRL)

Uric acid, bilirubin, total protein, A/G, SGOT

Lipids (NMRI)

Serology (LRC)

Vitamin D assay (Massachusetts General Hospital and Holmquest, MSC)

Hematology

CBC, differential

Hematocrit

Body fluids and lean body mass

Total body water (tritium)

Plasma volume (RISA)

Skin folds

General medical status checks (daily)

Private medical interview

Vital signs (temperature, pulse, blood pressure)

Body weight

EKG weekly

Exercise program

Pretest and posttest evaluation (Balke/Astrand-Rhyming)

Daily ergometer/Cardiotach. evaluation

Weekly ergometer oxygen consumption (Webb, MRM)

Pulmonary studies (LRC)

Forced vital capacity flow volume loop (weekly)

Alveolar air samples pretest, midrun and posttest

Sleep respiratory rates

Blind spot mapping (NASA Ames)

Urinalysis

Toxicology sample

Routine urinalysis

Total urine output

Urine electrolytes and acidity weekly (biweekly last 30 days)

Microbiology program

Potable water onboard monitoring

Wash water onboard monitoring

Cabin air and surfaces sampling

Nasal and pharyngeal samples

Pharyngeal wash (viral)

Skin sites

Potable water microbial monitor (Wilkins, LRC)

There were several changes before test start largely because of a change in medical direction after the 5-day run and partially as a result of Operational Readiness Inspection Committee (ORIC) considerations. The late addition of urine chemistry prevented acquisition of pretest baseline, complicating post-test analysis of the data. These chemistries were primarily directed at studying CO₂ exposure effects and had little impact on evaluations of crew health and safety. Several of the procedures will be reported elsewhere by the principal investigators.

RESULTS

Basal Biomedical Data

Basal oral temperature, body weight, blood pressure, and pulse rate were obtained daily as soon as possible after awakening and before breakfast. Crewmen (CM) accomplished the procedures onboard and reported the results to the medical monitor for recording (except oral temperature which was displayed at the medical console in the control room). There were no significant trends in either pulse rate or blood pressure. Oral temperature in crewmen 3 and 4 illustrates their adjustment to a reversed day-night cycle (fig. 1(a)). It would appear that this adjustment was not complete in respect to oral temperature for at least 2 weeks, perhaps longer. Body weight changes are illustrated in figure 1(b) and are adjusted for individual uniform weights. Short-term fluctuations probably represent alterations in state of body hydration. Taking these fluctuations into account it is likely that the only significant weight changes occurred in crewmen 2 and 4. Further changes occurred in the 21 days posttest resulting in a net gain in crewman 2 of 4.75 lb and a net loss in crewman 4 of 1.25 lb. In spite of these final changes, the net for the crew remained +2.25 lb. This probably represents a real weight gain in crewman 2 and a net loss in the remaining crew members. These weight changes are reflected in skin-fold thickness trends (fig. 2). Weekly electrocardiography revealed no significant trends. An arrhythmia was discovered in crewman 2 which was without medical significance but had been undetected before the test. Questioning revealed that crewman 2 had noticed this rhythm variant at least a year before.

Exercise Program

The crew exercise program was directed primarily at evaluation of bicycle ergometry in maintaining cardiovascular fitness. Exercise, however, was not restricted to ergometry and crewmen pursued personal programs of varying intensity. The basic regime consisted of daily (5 days/week) ergometer exercise at a predetermined submaximal workload. Resting heart rates for 5 minutes before exercise, during 15 minutes of exercise, and for 10 minutes of recovery were recorded. The workloads were originally established to produce peak heart rate responses of 150 to 160 beats per minute. These preset workloads were adequate for crewmen 1 and 4; inadequate to prevent excessive pedal speeds in crewman 3. The workload for crewman 3 was, therefore, increased. Crewman 2 devised his own program; for 30 days he relied on ergometry alone, for the next 30 days he increased his ergometer workload and performed an increasingly strenuous extra exercise program, and during the last 30 days he continued at the final ergometer workload with minimal additional exercise. Extra exercise by crewmen 1, 3, and 4 varied from minimal for crewman 1 to strenuous and steady for crewman 4, strenuous and less steady for crewman 3. Cardiovascular fitness was evaluated pretest and posttest by means of the Balke Optimal Work Capacity Test (table I). Figure 3(a) illustrates heart rate responses to ergometry during the run. The curves for individuals are inconclusive, but the group mean \bar{x} suggests a deconditioning trend. When the responses are corrected for

changing workload (H/W = Heart rate/Workload), however, an overall improvement is suggested. This improvement is supported by the trends toward increased oxygen consumption (fig. 3(b)) and by the posttest Balke scores. The latter demonstrates slight deconditioning in crewman 1, improvement in crewmen 2 and 4 and no change in crewman 3. In view of the extra exercise programs, it is concluded that constant-level legs - only exercise is probably insufficient for maintenance of cardiovascular fitness, as measured here, during prolonged confinement.

Clinical Biochemistry and Hematology

A clinical blood biochemistry battery (SMA-12) and a complete hematologic evaluation were performed biweekly. Figures 4 to 9 illustrate selected parameters from these tests.

Figure 4 illustrates blood urea nitrogen (BUN) and alkaline phosphatase. Each individual serves as his own control with limits determined by the pretest mean \pm "t" standard deviations; the "t" value based on the number of pretest samples. There were no significant changes in serum alkaline phosphatase. All BUN's are within laboratory limits of normal, but significant elevations are seen in crewmen 3 and 4 in respect to their own control limits. The elevations in crewman 3 are fairly constant and are still being evaluated; the elevations in crewman 4 are less constant. It should be noted, however, that the time of sampling in crewmen 3 and 4 is late afternoon in their day-night cycle as opposed to a fasting morning sample pretest and in crewmen 1 and 2. This variable makes evaluation of chemical changes most difficult. It is concluded that the BUN changes are probably of no clinical significance.

Serum albumin and albumin-globulin (A-G) ratios are illustrated in figure 5. All crewmen show a depression in A-G ratio on day 39. The outside control crewman showed the same drop, however, and the "change" is without significance.

Serum glutamic oxalacetic transaminase (SGOT) and lactic dehydrogenase (LDH) are illustrated in figure 6. Crewmen 2, 3, and 4 demonstrate significant changes. The initial elevations in crewman 2 are not only statistically significant but also reach values ordinarily considered pathologic and were confirmed by another laboratory. These enzymes are used as indicators of cellular damage but we have no other evidence for such damage. Crewman 2 had experienced considerable work stress during the first week of the test and we are hypothesizing a relationship with that stress, coupled with physical fatigue.

Serum calcium and inorganic phosphorus trends are illustrated in figure 7. Complete analysis of these data are incomplete, but they suggest significant changes in calcium-phosphorus metabolism. The trend suggests an initial depression in serum calcium, followed by a rise to a peak on day 39 and a subsequent downward trend. Serum phosphorus reflects the calcium changes. A relationship to CO₂ exposure is possible and is being investigated by further analysis.

Hematological changes (fig. 8) in crewmen 1 and 2 are unremarkable. Crewman 3, however, demonstrated a disconcerting drop in erythrocytes, hematocrit, and hemoglobin on day 25 followed by consistently low values for him. Crewman 4 shows some of these changes also. Again, these may be related to diurnal variation or to the preceding exercise. Haptoglobins in these crewmen do not clearly suggest a hemolytic cause. The combination of low hematocrit, elevated BUN, and mild stomach symptoms in crewman 3 suggested the possibility of gastrointestinal bleeding. He also reports a family history of peptic ulcer and a previous concern for the possibility of that disease in himself. A stool specimen obtained on day 32 was negative for blood, but the specimen was small. At this writing we are continuing our evaluation but the whole syndrome may only represent a diurnal phenomenon.

Urine Chemistry

Twenty-four hour urine collections were made weekly until day 53, then biweekly. A 10 percent aliquot of each voiding was collected and frozen for pass-out. Part of the sample was separated after pass-out and saved for toxicological contingencies. The remainder was subjected to routine urinalysis and biochemical analysis for sodium, potassium, chloride, calcium, inorganic phosphorus, total titratable acidity, ammonia, and pH. Titratable acidity and pH reveal no discernible trends as neither do calcium, phosphorus or Ca-P ratios (figs. 9(a) and (b)). All these data, however, will be subjected to analysis of variance for possible relevance to CO₂ exposure. There is none apparent in these figures or in scatter plots developed during the test. Figure 9(c) illustrates sodium/potassium excretion ratios. Na/K is related to aldosterone production and changes may be related both to diurnal cycle changes and to stress. We are evaluating these relationships, but have only preliminary impressions at this writing. Sodium excretion relative to potassium appears to be consistently lower in crewmen 3 and 4 for nearly the first two thirds of the test. This depression of the mean for the two crewmen is primarily a reflection of the Na/K in crewman 3 who may have recycled biochemically much more slowly than was apparent subjectively or in his basal signs. A peak is clear in all crew members at day 74. This point in the test follows a period of subjective crew stress which reached its culmination in a "sensitivity session" on day 69. Sodium/potassium ratio as an indicator of stress as well as an indicator of aldosterone production, per se, is still under study.

CONCLUDING REMARKS

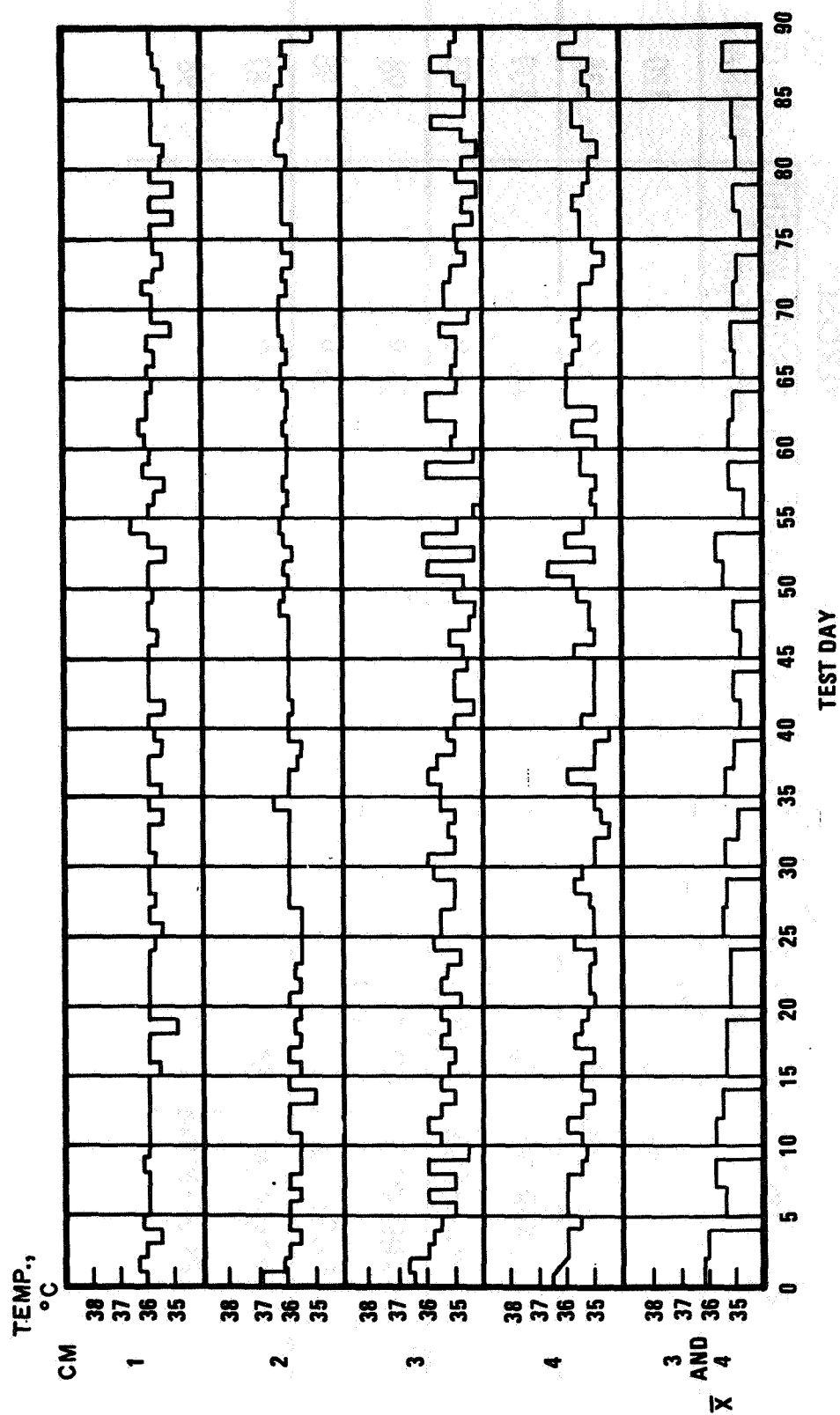
Medical procedures described here, as supplemented by other investigations reported elsewhere, were quite adequate for monitoring crew health and safety. The changes observed are interesting and under further analysis but seem to be irrelevant to the overall test conditions, that is, the SSS environment was medically benign. Because of the essentially benign environment, it appears that 90 days is probably too short a period for complete evaluation of reactions to intermittent stress or to low-level environmental variables, for

example, low-level CO₂ exposure. Some of the data are suggestive of basic biochemical responses, as for example, apparent calcium-phosphorus metabolism changes and deserve further study. The use of urinary Na/K appears to offer potential as a simple stress indicator and also deserves further evaluation.

TABLE 1.- BALKE OPTIMAL WORK CAPACITY TEST

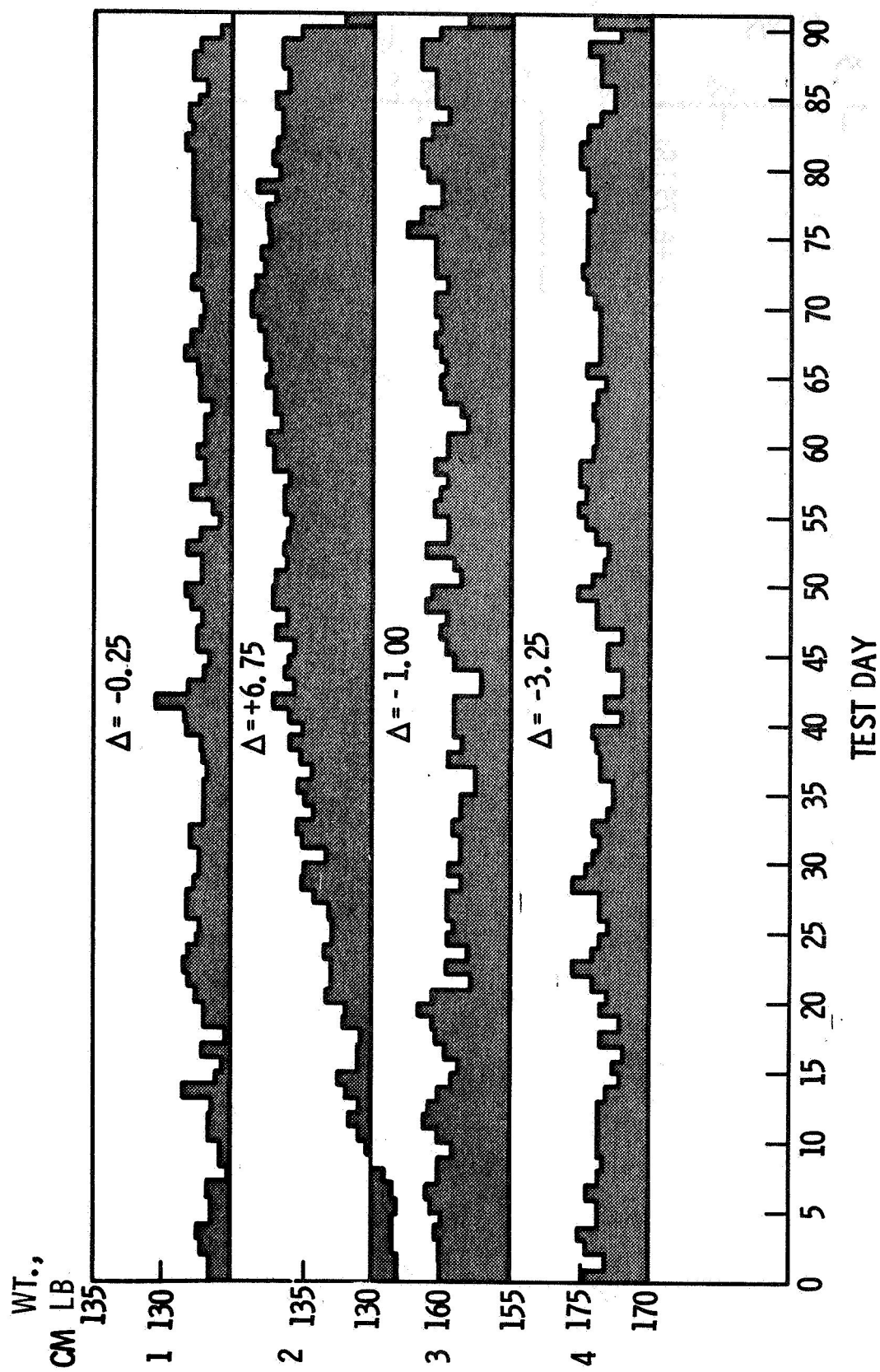
[TREADMILL SPEED = 3.5 MPH; TERMINATION HEART RATE = 180 BEATS/MIN]

CREWMAN	TIME	WEIGHT (Kgm)	TIME ON TREADMILL (min)	FINAL MINUTE OF EXERCISE		BALKE INDEX (% OF AVERAGE)
				TOTAL WORK (Kgm-m/min)	WORK/Kgm OF BODY WEIGHT (Kgm-m/min/Kgm)	
4	PRE-RUN>	81.7	22	1688	20.3	120
	POST-RUN>	80.5	25	1887	23.2	135
1	PRE-RUN>	58.9	20	1103	18.8	109
	POST-RUN>	58.9	17	940	16.0	93
3	PRE-RUN>	73.7	18	1248	16.9	98
	POST-RUN>	74.1	18	1252	16.9	98
2	PRE-RUN>	59.2	16	888	15.0	87
	POST-RUN>	61.9	18	1043	16.9	98



(a) Oral temperature.

Figure 1.- Basal biomedical data.



(b) Body weight.

Figure 1.- Concluded.

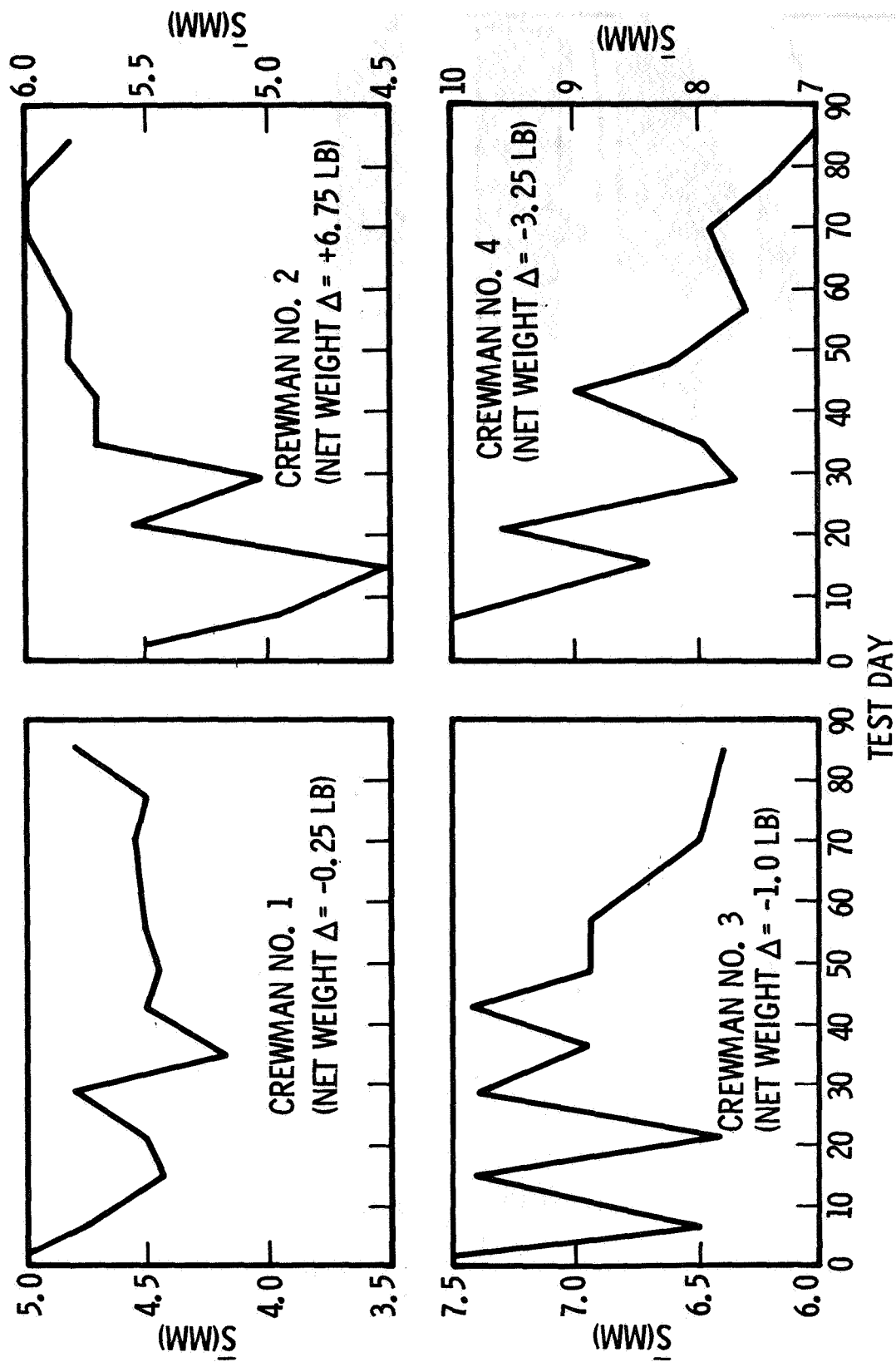
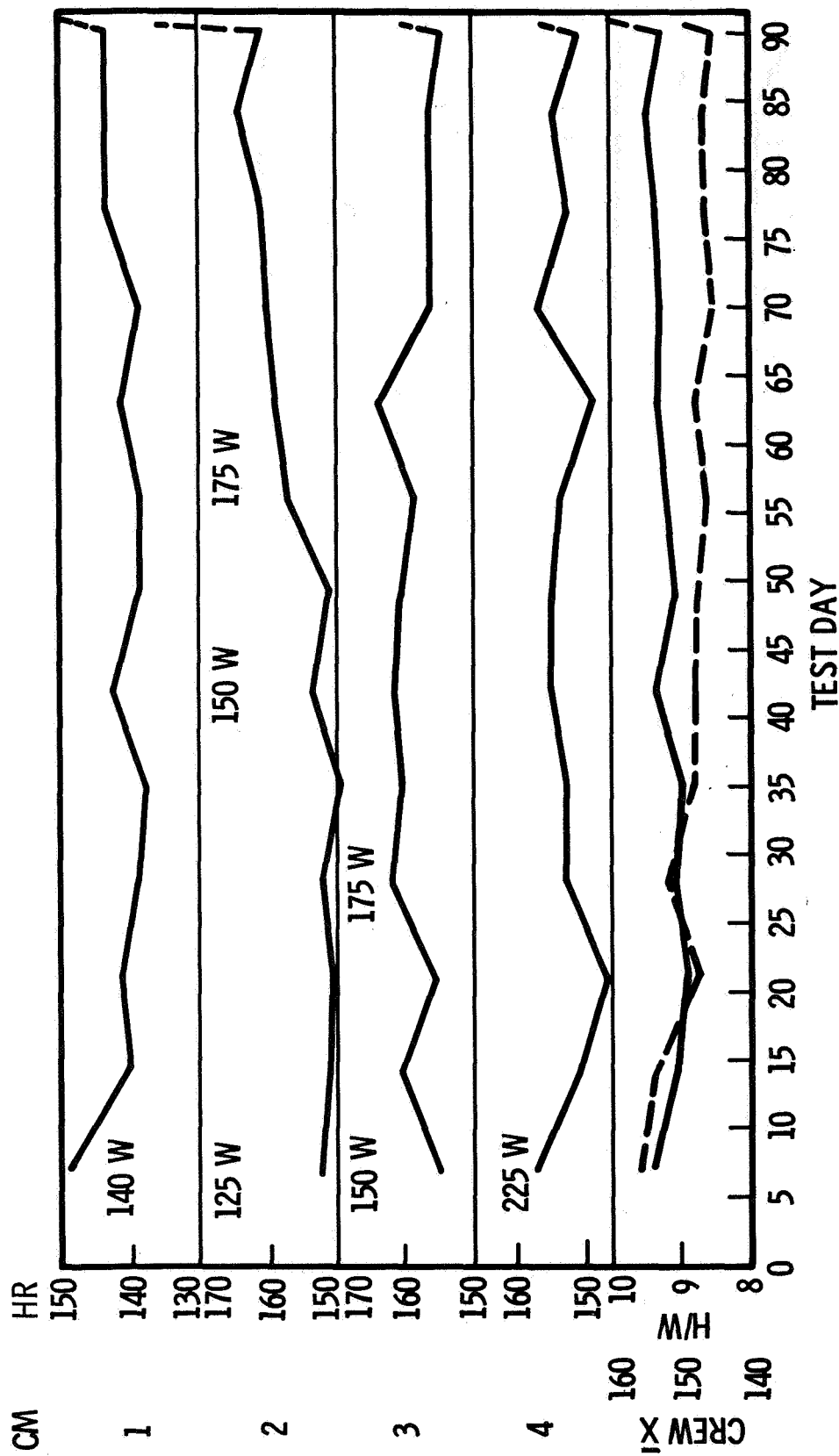
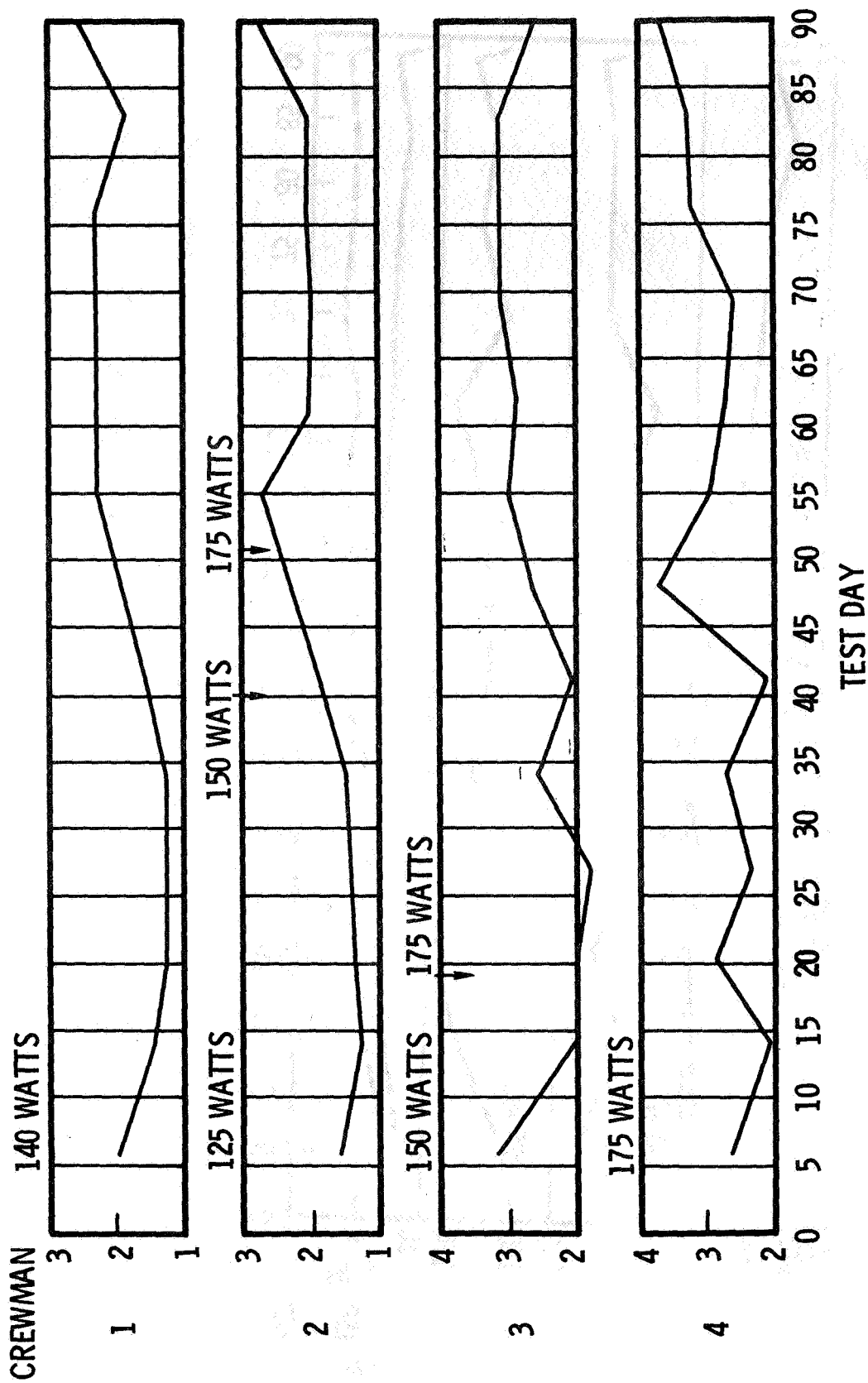


Figure 2.- Skin fold trends.



(a) Peak heart rates, weekly mean.

Figure 3.- Bicycle ergometer exercise response.



(b) Peak oxygen consumption, liters/min.

Figure 3.- Concluded.

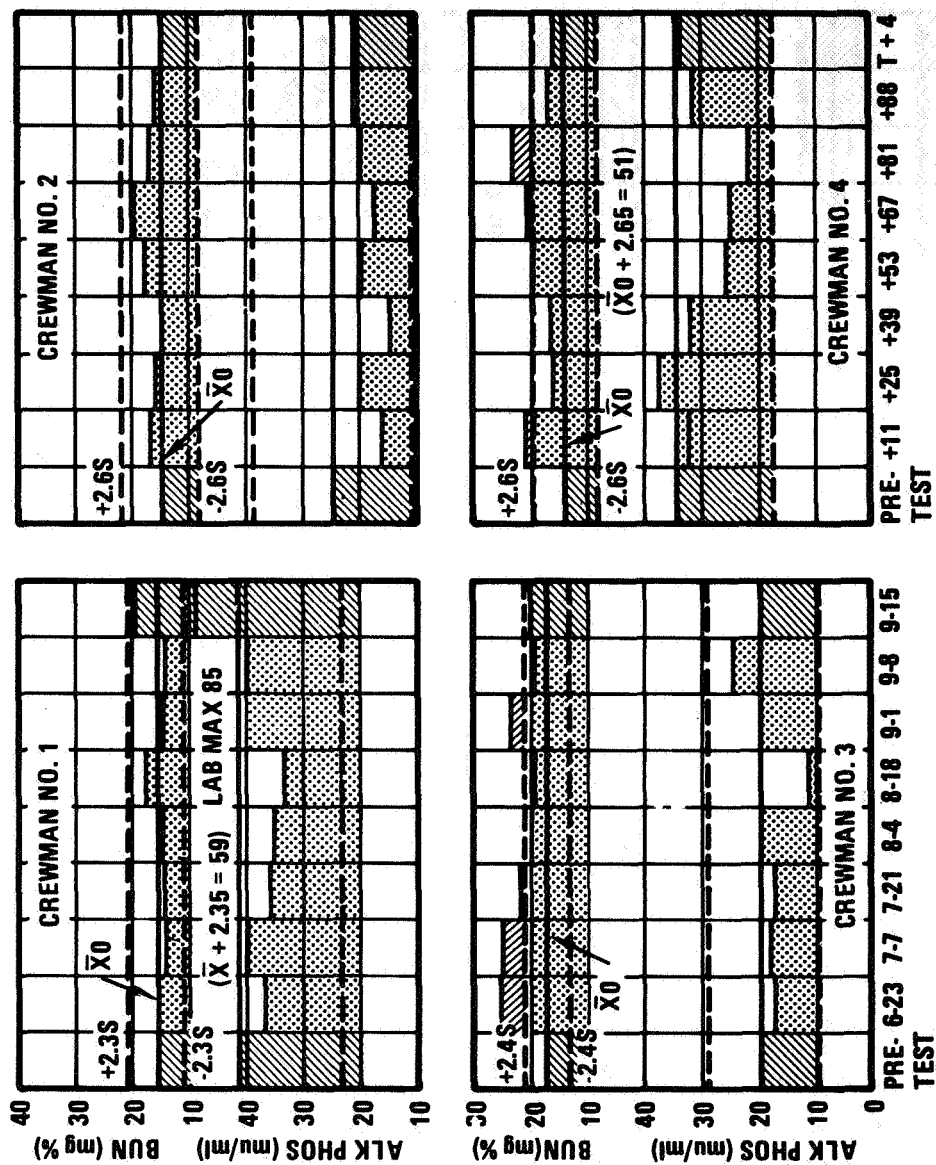


Figure 4. - Blood urea nitrogen and alkaline phosphatase.

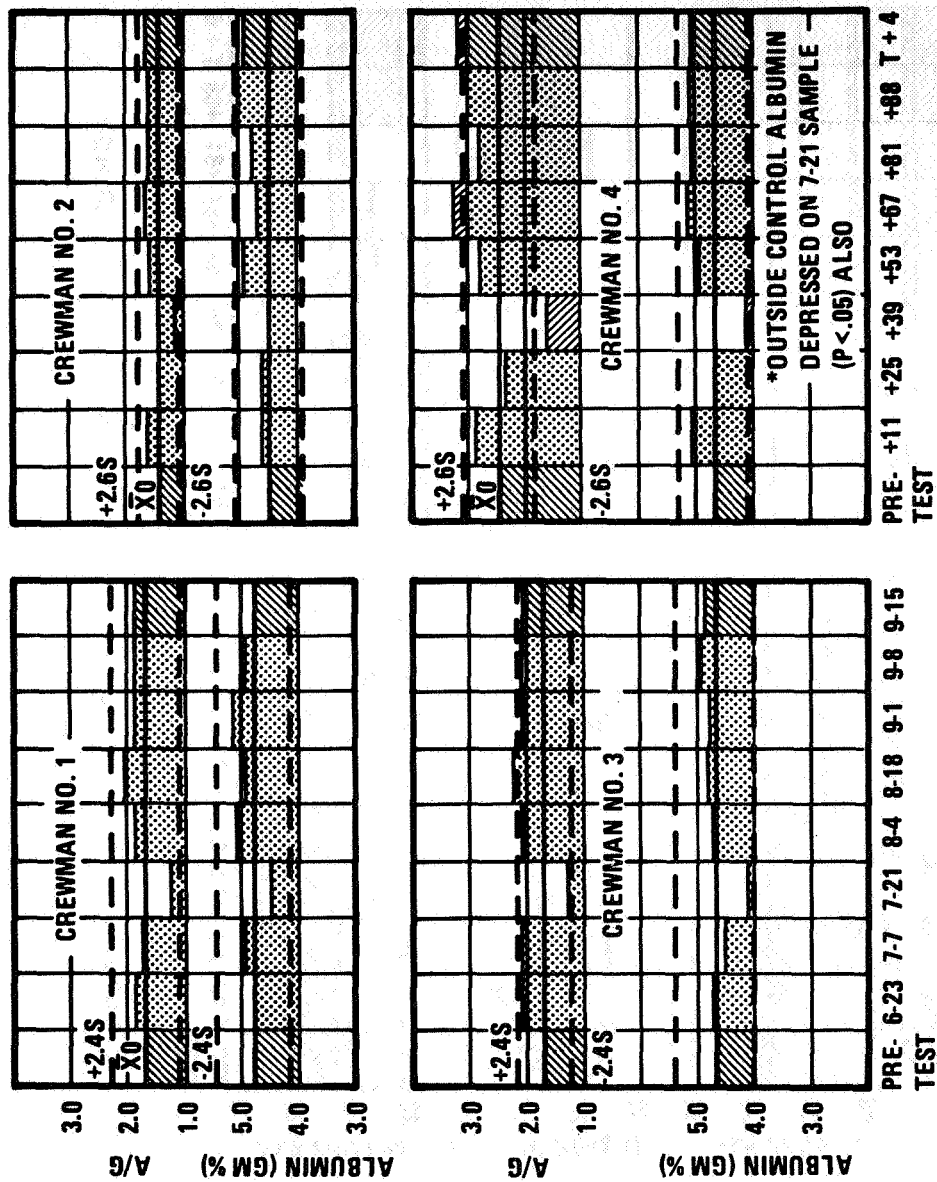


Figure 5. - Serum albumin and albumin-globulin ratio.

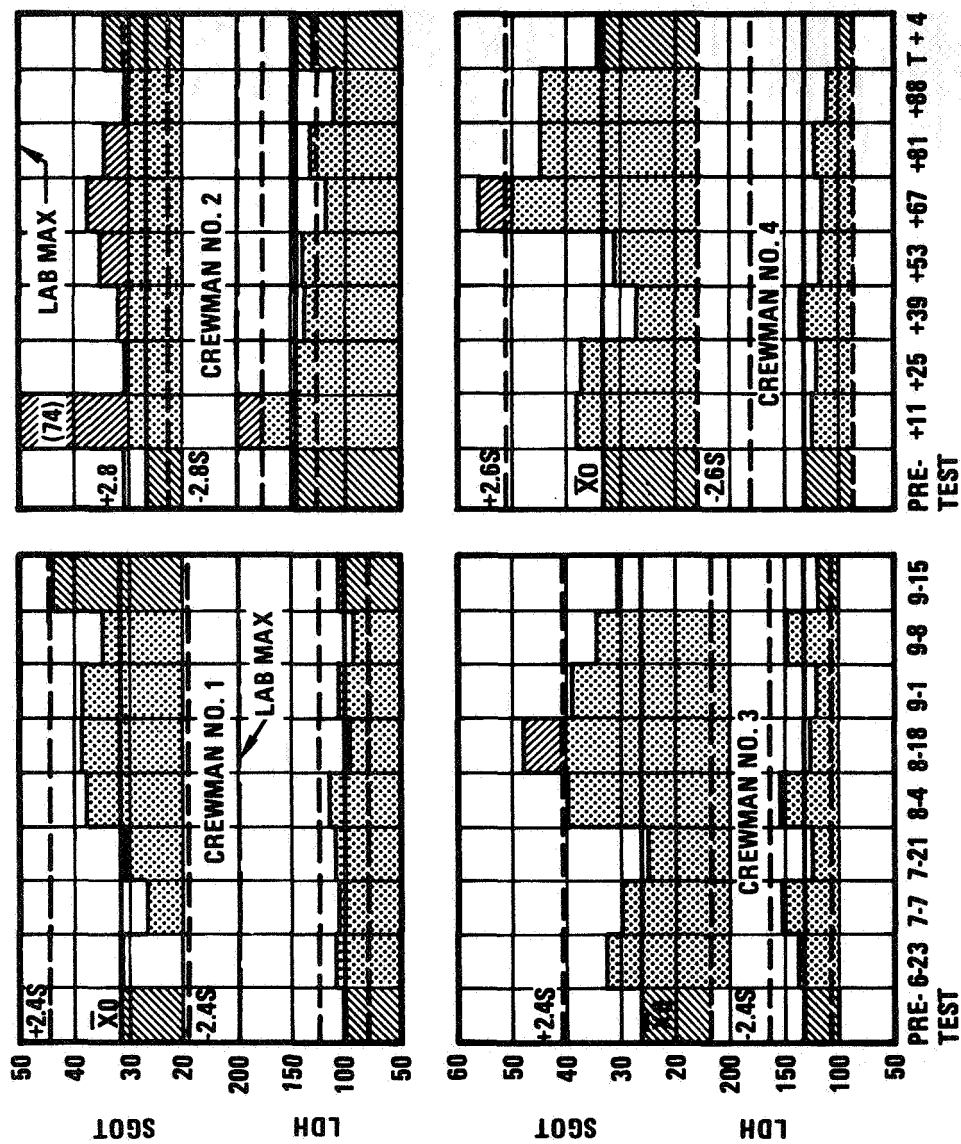


Figure 6.- Serum enzymes, SGOT and LDH.

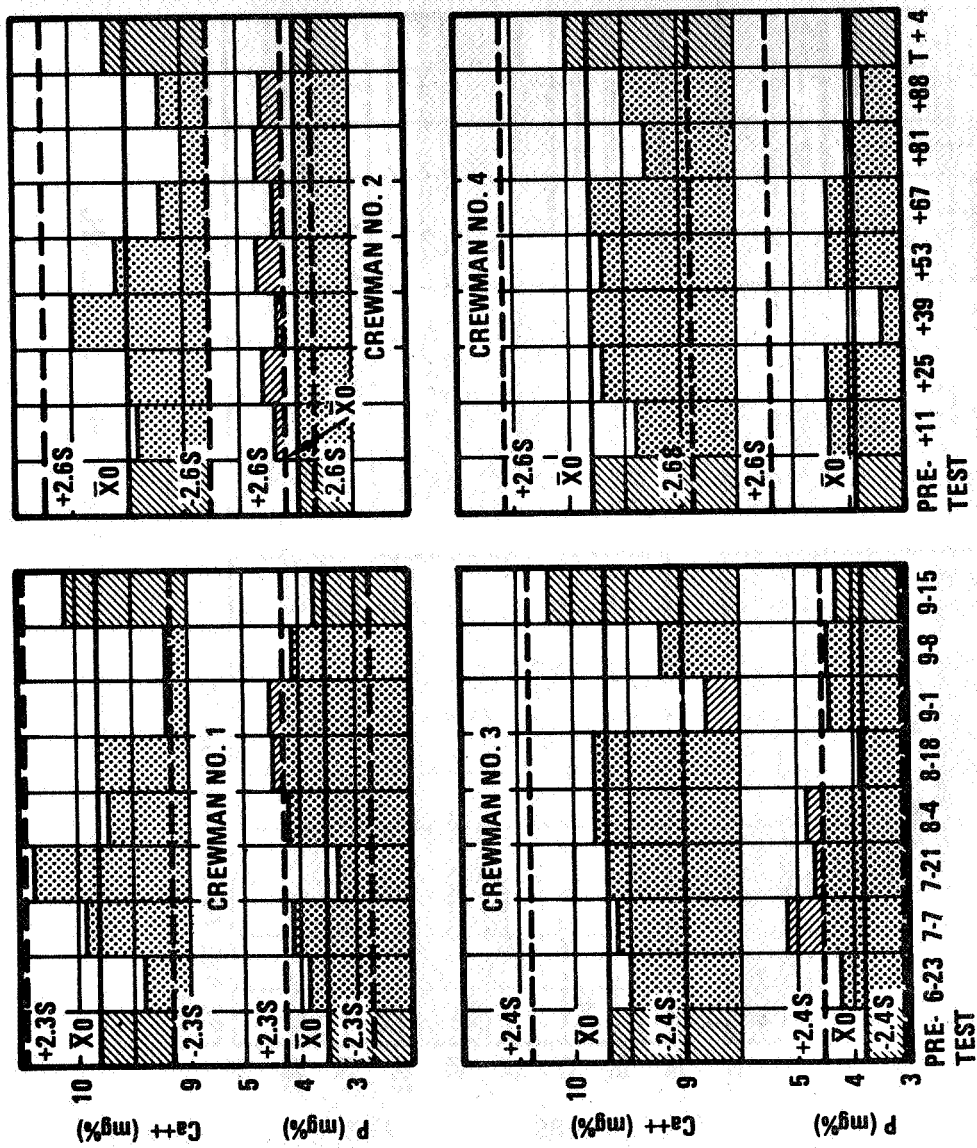
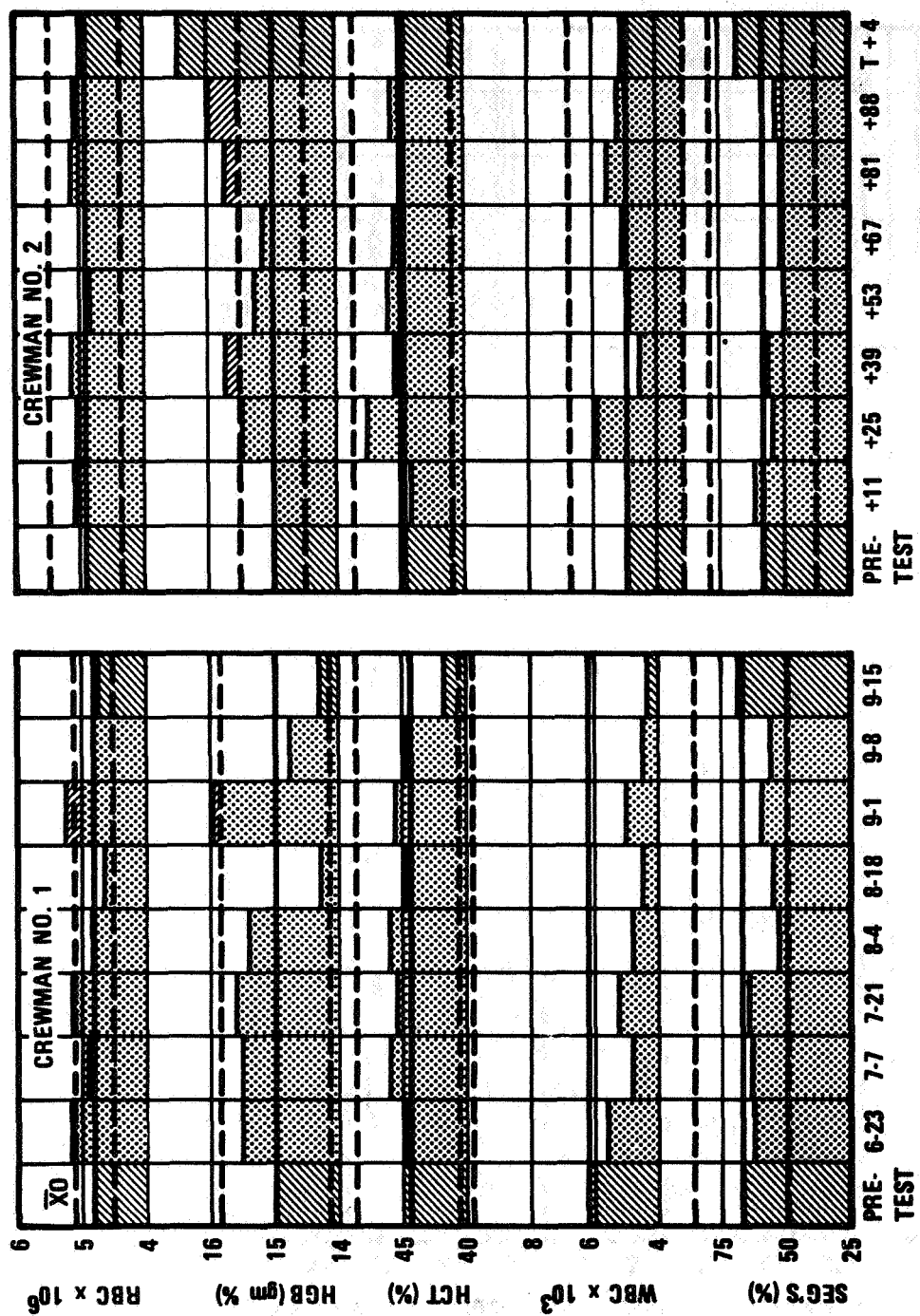
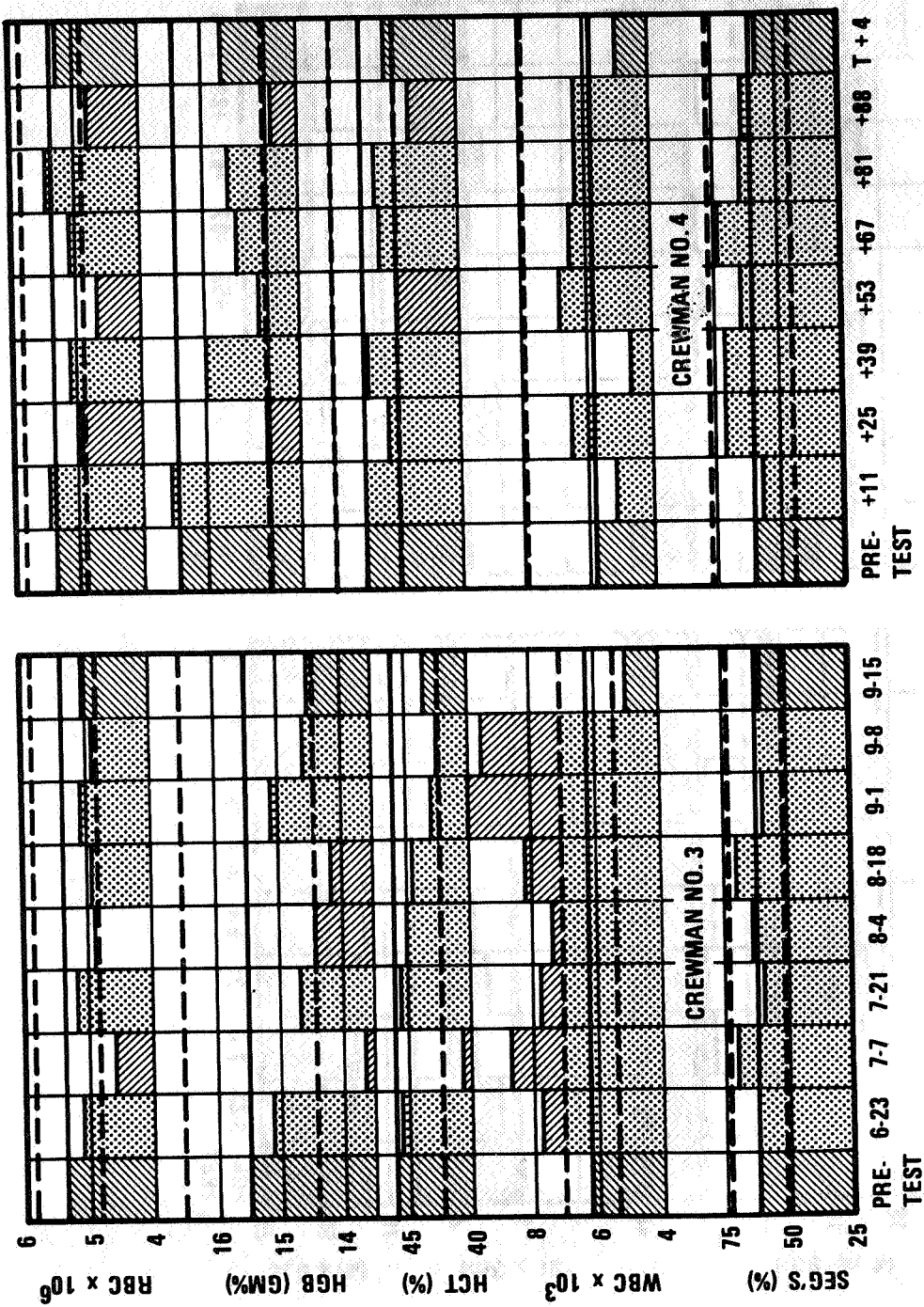


Figure 7.- Serum calcium and inorganic phosphorus.



(a) Crewmen 1 and 2.
Figure 8.- Hematology summary.



(b) Crewmen 3 and 4.

Figure 8.- Concluded.

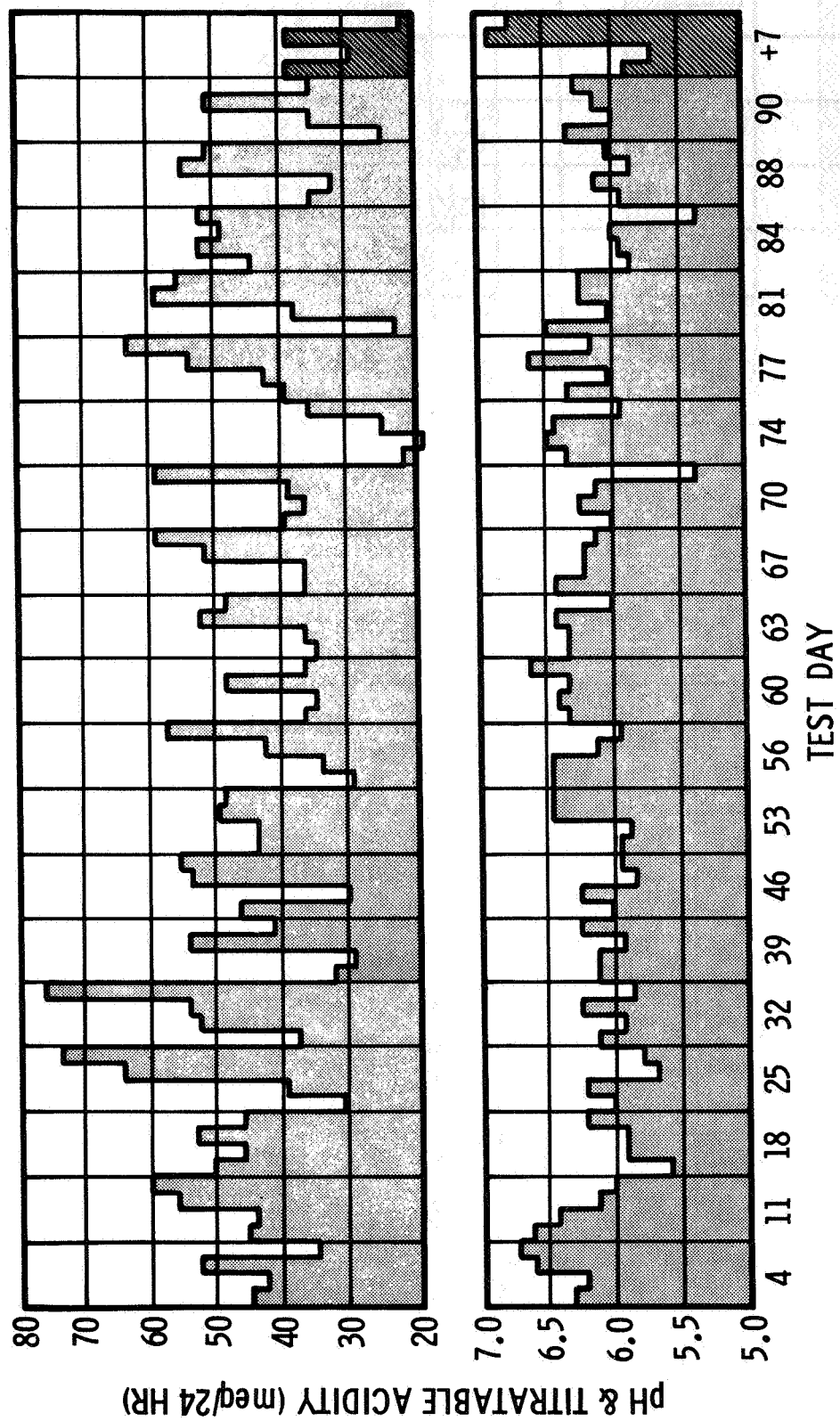


Figure 9.- Urinary excretion patterns.

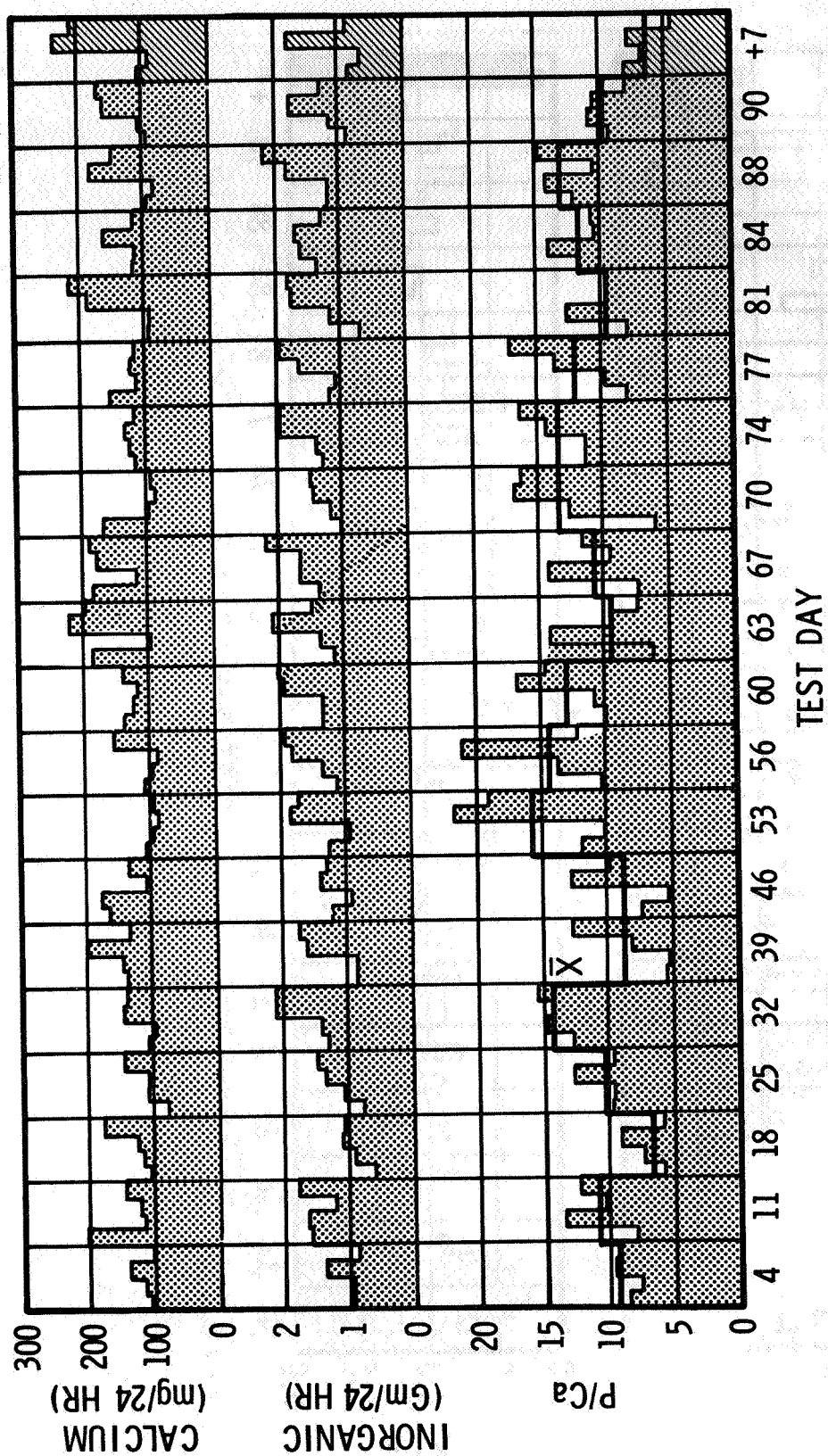


Figure 9. - Continued.

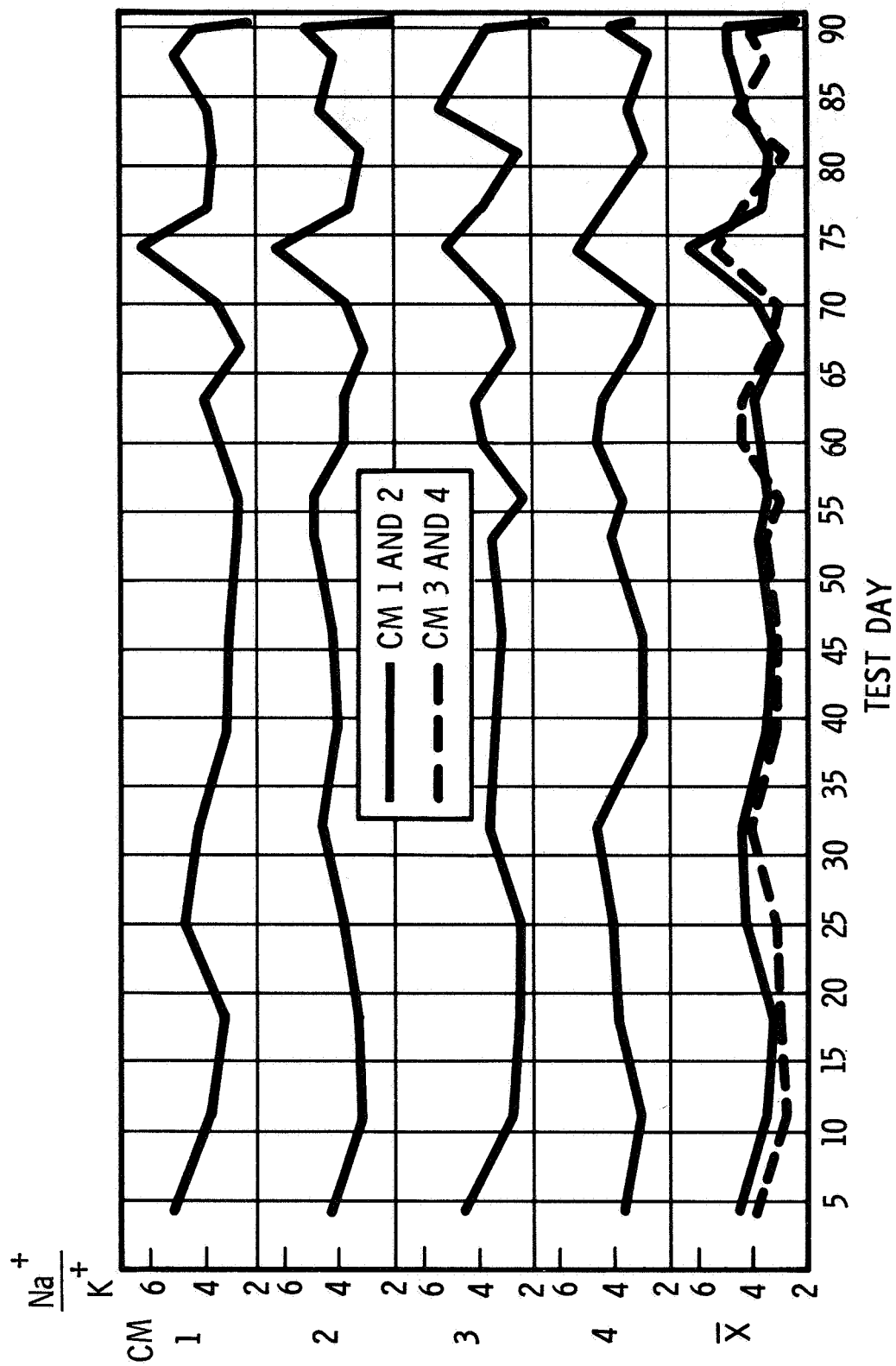


Figure 9. - Concluded.

MICROBIOLOGY RESULTS - DERMAL AND ENVIRONMENTAL SAMPLING

By K. J. Levinson

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SUMMARY

The 90-Day SSS test offered unique opportunities for obtaining long-term microbiological data in an isolated environment. An illustration of the sampling protocol utilized for the microbiology program is presented. Skin sites were swabbed weekly to determine potential shifts in normal microflora. No significant quantitative alterations were found and there were no observable shifts in predominant isolates. Reynier air samples and surface swab samples were used to obtain microbial counts and identification of predominant types. The predominant organisms in both of these types of environmental samples remained those carried by the crew members. An increase in number of types but not in number of viable particles in atmospheric samples coincided with catalytic burner shutdown and may be coincidental and unrelated to that occurrence. Post-test sampling of hardware and surfaces was accomplished but results are not yet available.

INTRODUCTION

There were four unique characteristics of the 90-Day SSS test which enhanced the microbiological data obtained from the experiment. A truly microbiologically closed system was maintained by operating the autoclave in the pass-through port for 30 minutes after each weekly passout. There was no pre-test quarantine period for the crew, so that any potential exchange of microflora could be followed from the outset of the test. Also, this provided the opportunity for the inclusion of "off-the-street" microorganisms into the ecology of the simulator. Another important feature was the rapid processing of samples with a maximum lag period of 1 hour between collection and primary incubation for nasopharyngeal cultures and 1.5 hours for the dermal anaerobic plates.

MATERIALS AND METHODS

Figure 1 illustrates the sampling protocol utilized for the microbiology program. Nasopharyngeal materials, methods, and results are discussed in paper no. 35 of this compilation.

Three dermal sites were chosen for study, the axilla, perineum, and the first interdigital space of the right foot. The crewmen were trained prior to the test in sterile technique and proper sampling procedures. Consistency in technique was stressed. Saline-moistened cotton-tipped swabs were used to

obtain specimens immediately prior to the passout each week of the test. Specimens were swabbed to blood agar and differential and selective media for aerobic and anaerobic bacteria and fungi. After appropriate primary incubation, the isolates were described, assigned numbers, streaked for purification, and transferred to Trypticase Soy Agar (TSA) slants for shipment to Langley Research Center (LRC) for identification.

Contaminated Millipore water monitors incubated in the on-board laboratory were passed out of the simulator, growth streaked for isolation, and transferred to slants for identification.

Reynier air samplers were operated every 2 weeks for 1 hour in the forward (equipment) area and the aft (crew) compartment at a flow rate of 1 ft³/minute. The TSA Reynier plates were incubated 24 hours and a representative of all morphologically different isolates was picked for identification.

Surface areas 4 inches square (16 square inches) in the food management and hygiene compartments were swabbed with Trypticase Soy Broth (TSB) moistened swabs, and the specimens were passed out and plated to blood agar, MacConkey's Agar, Staphylococcus #110 Medium, TSA, and Sabouraud Dextrose Agar.

Post-test swabs of selected hardware and equipment surfaces were plated to the appropriate media to recover aerobic and anaerobic bacteria and fungi. Components of life support subsystems (such as charcoal and particulate filters) were inoculated to TSB and Brewer's Thioglycollate Broth for initial incubation and then plated to the differential and selective media.

OBJECTIVES

The following determinations constituted the dermal and environmental microbiological objectives of the 90-day test:

- (1) Gross quantitative shifts in aerobic and anaerobic dermal flora of the skin sites
- (2) Qualitative alterations in the composition of the microbial flora of individual skin sites
- (3) Exchange of flora between crewmen or between dermal sites
- (4) Counts and types of environmental microbiological contamination

RESULTS

No significant quantitative alterations were found in dermal aerobic or anaerobic bacterial flora or in the fungal flora. Very consistent growth scores on the primary isolation media were obtained throughout the 90-day test.

There were no observable shifts in the predominant dermal isolates throughout the run. Staphylococcus epidermidis was recovered from each site of each crewman on every sampling period. Other members of the dermal flora were identified as members of the genera Micrococcus, Corynebacterium, Bacillus, Sarcina, and Aerococcus. Gram negative enterics, usually E. coli, were recovered, primarily from the perineal region.

Two dermal regions, the axillary and perineal, exhibited microbial profiles unique to each crew member. These profiles were maintained throughout the test, and no exchange among the crewmen or their individual skin sites was noted. The interdigital spaces of all four crewmen were consistently similar in their aerobic floral composition. These findings are also illustrated in the recovery of obligate anaerobes from the skin sites.

Table I indicates the number of obligate anaerobes recovered from each sampling period and dermal site. The axilla and perineum of all crewmen consistently yielded anaerobes, preliminarily identified as "anaerobic diphtheroids". However, the toe web of each crewman remained conspicuously absent of obligate anaerobes. The perineum of crewman 4 consistently yielded, in addition to anaerobic diphtheroids, large numbers of Bacteroides melanogenicus.

Staphylococcus aureus has been the subject of many epidemiological studies, including those conducted on Apollo astronauts. This potentially pathogenic microorganism is carried by a large percentage of the population, primarily in the nasal region. It has been recently revealed that the skin, especially the perineal region, also harbors S. aureus. Table II shows data indicating the sporadic presence of this organism on all skin sites. Coagulase positive S. aureus isolated from Tellurite Glycine Agar at MDAC's laboratory are indicated by a +. Mannitol positive, coagulase positive or negative S. aureus identified as such from isolates sent to Langley Research Center are indicated by 0. Although crewman 2 remained the predominant nasal carrier of S. aureus throughout the test, crewman 4 yielded this organism from skin sites most frequently.

Microorganisms shed from the skin of inhabitants of closed environment are an important source of atmospheric and surface contamination. Therefore, it is not surprising that the predominant member of the crewmen's skin flora, Staphylococcus epidermidis, was also the predominant isolate from the simulator air and surfaces. To complete the epidemiological study utilizing S. aureus, contamination by this organism was also followed in the air and on the surfaces. Table III indicates the dates of recovery from each sampling site. Whether or not the source of this contamination was generated by the crewmen's dermal S. aureus or those residing in their nasopharynx remains open to speculation, since phage and antibiotic-resistance typing proved unsuccessful.

Figure 2 illustrates the microbial counts obtained from Reynier air samples. Atmospheric counts remained low (less than 3 microorganisms/ft³ of air) throughout the test. Precounts and postcounts were extremely low (less than 0.2 microorganisms/ft³ of air) indicating that the crewmen were the sole source of atmospheric contamination. During the period that the catalytic toxin burner remained inoperative, atmospheric counts rose slightly in the forward section

(where the burner was located); however, aft section counts dropped or remained the same. Fungal counts remained extremely low in both sections throughout the test. Maximum counts occurred on the 46th test day and consisted of 0.12 organisms/ft³ of air in the forward section and 0.23 organisms/ft³ of air in the aft compartment.

Although the catalytic burner shutdown did not influence microbial air counts significantly, figure 3 illustrates a coinciding increase in the number of different bacterial types isolated from the air of the forward compartment. Microorganisms identified as Alcaligenes sp., Neisseria catarrhalis, Enterobacter Group B and Proteus mirabilis were not isolated from the air before the 10th week of the test. Whether or not this increase in bacterial types represents a natural buildup of bacterial species or is a result of the inoperation of the catalytic burner remains open for further investigation. The latter seems unlikely.

Figure 4 illustrates bacterial surface counts from the food management and hygiene areas. Bars which extend to 30 organisms/in² of surface area represent plate scores which were too numerous for accurate counting. Significant buildups of contamination occurred on six occasions in the crew hygiene area. Fungal counts were also high in the hygiene area in comparison with the food management area. No fungi were isolated in the food management area until midway through the test, and the count remained low until test completion.

Listed in decreasing order of occurrence in table IV are the predominant bacteria contaminating the surfaces. Staphylococcus epidermidis was recovered on every sampling date, excepting one, from both the food management and the hygiene areas. Species of Bacillus were the next most common isolate followed by the gram positive Sarcina and Micrococcus. Gram negative bacteria were completely restricted to the hygiene area except on 14 July when all three types, Aerobacter, Alcaligenes, and Pseudomonas were found in the food management area. This gram negative contamination coincides with the only significant contamination buildup in the food management area which also occurred on 14 July.

Figure 5 shows the areas investigated during the post-test microbiology study. Organisms in all three categories were recovered. At this writing, isolates are being identified and analysis of the results will begin as soon as identifications are completed.

TABLE I

OBLIGATE ANAEROBES ISOLATED FROM DERMAL SITES OF CREWMEN

CREW- MAN	SITE SAMPLED	DATE OF COLLECTION (1970)															(POST-TEST)
		6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8	9/29	
		(PRETEST)															
1	AXILLA	-	0	1	1	1	1	2	2	2	1	0	2	0	1	2	
	PERINEUM	1	-	1	1	1	0	2	1	2	1	1	0	2	1	2	
	TOE WEB	1	-	0	0	1	0	0	0	0	0	0	0	1	0	0	
2	AXILLA	1	1	0	0	0	1	1	0	1	0	0	1	2	1	0	
	PERINEUM	2	0	1	1	1	0	1	1	1	1	1	1	1	1	1	
	TOE WEB	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	AXILLA	0	0	1	2	0	2	1	2	3	1	1	2	1	2	1	
	PERINEUM	0	0	1	0	0	0	0	0	1	1	0	5	1	1	1	
	TOE WEB	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	
4	AXILLA	0	0	0	2	1	1	1	1	2	1	2	3	1	1	1	
	PERINEUM	4	3	4	5	3	3	3	3	4	4	3	3	3	4	3	
	TOE WEB	2	1	0	0	0	0	0	0	1	1	0	0	1	0	0	

TABLE II

RECOVERY OF STAPHYLOCOCCUS AUREUS FROM DERMAL SITES OF CREW MEMBERS

CREW- MAN	SITE SAMPLED	DATE OF COLLECTION (1970)														
		6/9 (PRETEST)	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8	9/29 (POST-TEST)
1	AXILLA	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-
	PERINEUM	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-
	TOE WEB	-	-	-	-	-	+	+	-	0	-	-	-	0	-	-
2	AXILLA	-	-	-	-	-	-	+	-	0	-	-	-	-	+	-
	PERINEUM	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-
	TOE WEB	-	-	-	-	-	+	+	-	0	-	0	0	-	-	-
3	AXILLA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PERINEUM	-	-	-	-	-	-	-	-	-	-	+	0	-	-	-
	TOE WEB	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
4	AXILLA	-	-	+	-	-	■	■	■	-	0	■	-	0	-	-
	PERINEUM	-	-	-	-	-	-	■	■	-	-	■	-	-	0	+
	TOE WEB	-	■	■	-	-	-	-	0	0	-	-	-	-	-	+

+ = MDAC LAB

0 = LRC LAB

■ = BOTH LABS

TABLE III

RECOVERY OF STAPHYLOCOCCUS AUREUS FROM SSS ATMOSPHERE AND SURFACES

SAMPLING SITE	DATE OF COLLECTION (1970)													
	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8
FOOD MANAGEMENT AREA SURFACE	-	-	-	-	-	-	-	-	+	-	-	-	-	-
HYGIENE AREA SURFACE	-	-	-	-	-	-	-	-	-	+	+	+	-	+
EQUIPMENT COMPARTMENT AIR (FORWARD)	-	-	-	-	-	+	-	-	-	-	-	+	-	+
CREW COMPARTMENT AIR (AFT)	-	-	-	-	-	-	-	-	-	-	-	+	-	-

TABLE IV

ORGANISM	SITE SAMPLED	DATE OF RECOVERY (1970)														
		6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8	9/11
<u>STAPHYLOCOCCUS EPIDERMIDIS</u>	FOOD MANAGEMENT	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
	HYGIENE AREA	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+
<u>BACILLUS SP.</u>	FOOD MANAGEMENT	+	-	+	-	-	-	+	+	+	+	+	-	-	-	-
	HYGIENE AREA	-	-	-	-	+	+	-	-	-	+	+	+	-	+	-
<u>SARCINA SP.</u>	FOOD MANAGEMENT	+	-	+	-	-	+	-	-	-	+	-	-	+	-	-
	HYGIENE AREA	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-
<u>AEROBACTER SP.</u>	FOOD MANAGEMENT	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	HYGIENE AREA	-	-	+	-	-	-	+	+	+	-	-	+	+	-	-
<u>MICROCOCCUS SP.</u>	FOOD MANAGEMENT	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
	HYGIENE AREA	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-
<u>ALCALIGENES SP.</u>	FOOD MANAGEMENT	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	HYGIENE AREA	-	-	-	+	+	+	+	+	-	-	-	-	-	-	+
<u>PSEUDOMONAS SP.</u>	FOOD MANAGEMENT	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	HYGIENE AREA	-	-	-	-	-	+	+	+	+	+	-	-	-	-	-

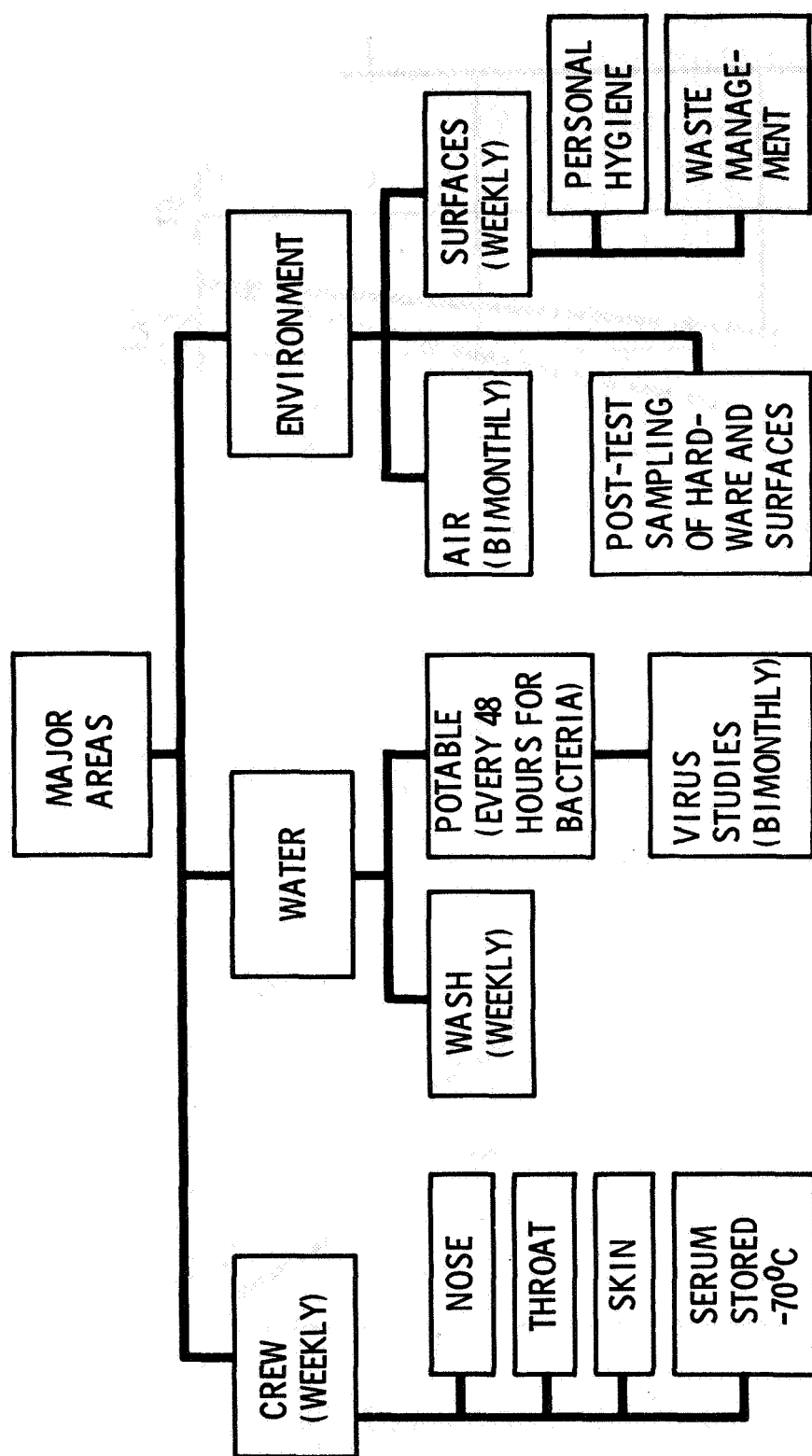


Figure 1. - Microbiology sampling protocol.

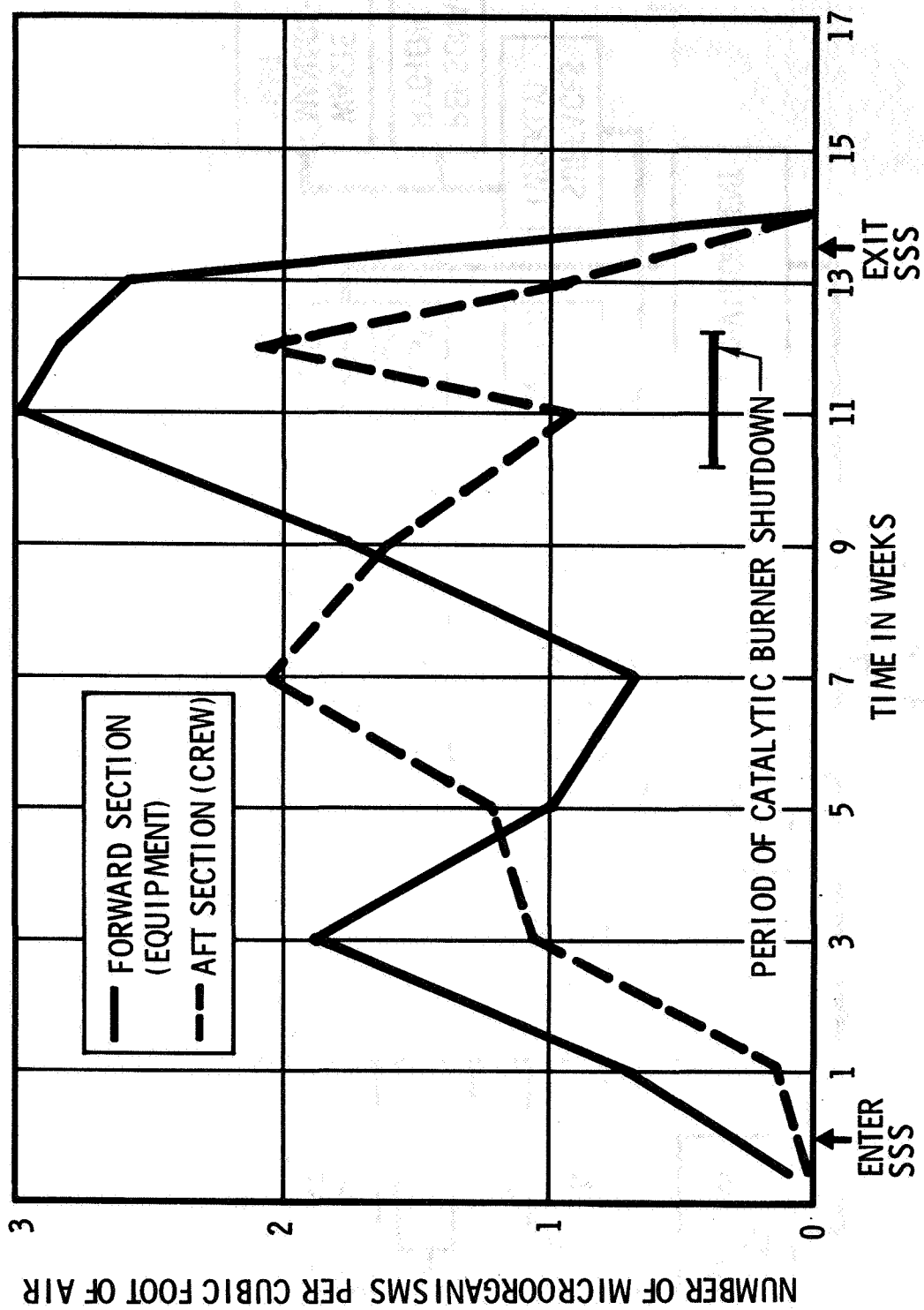


Figure 2.- Microbial counts from SSS atmosphere sampling.

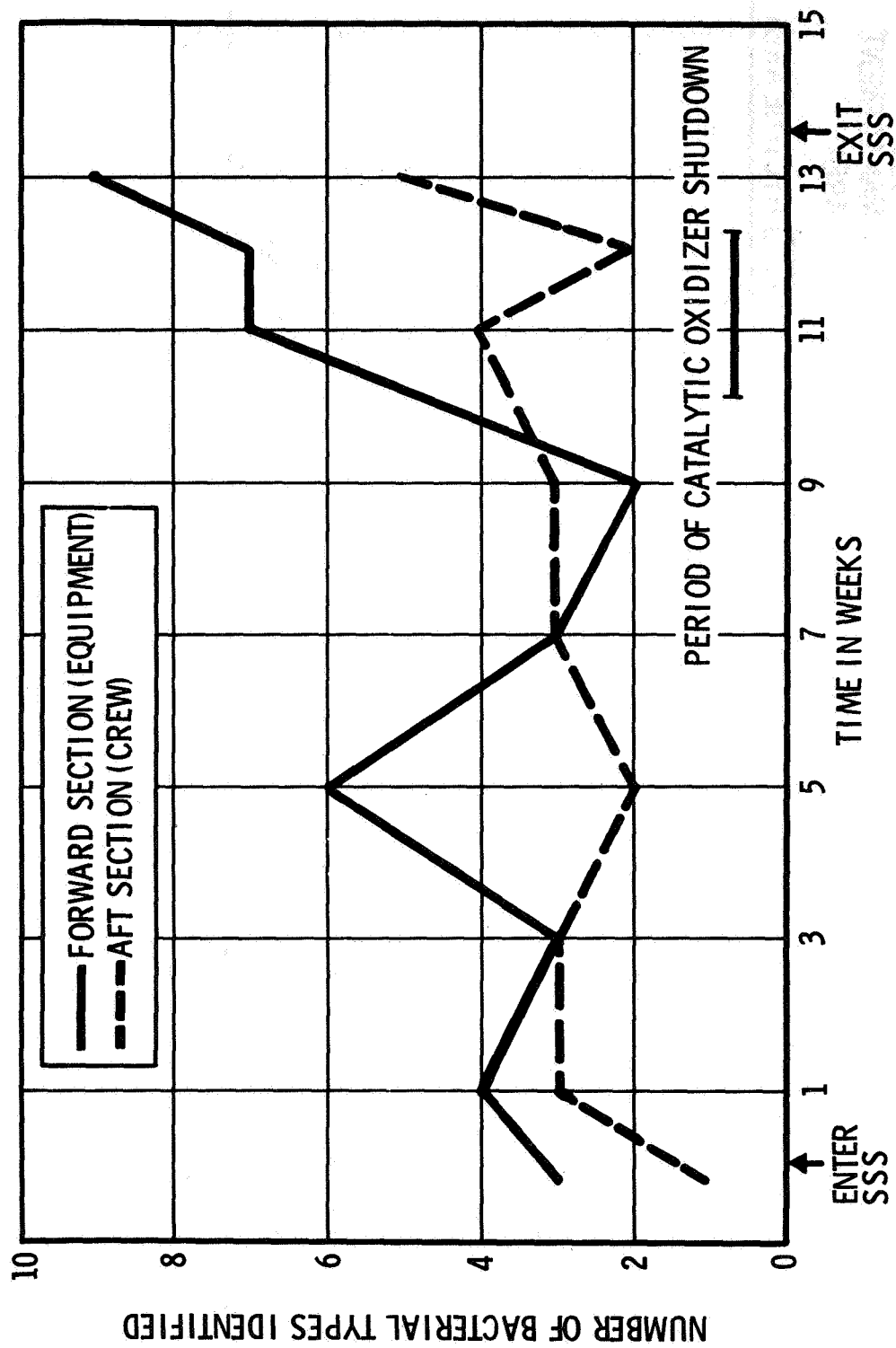


Figure 3. - Increase in bacterial flora of SSS air.

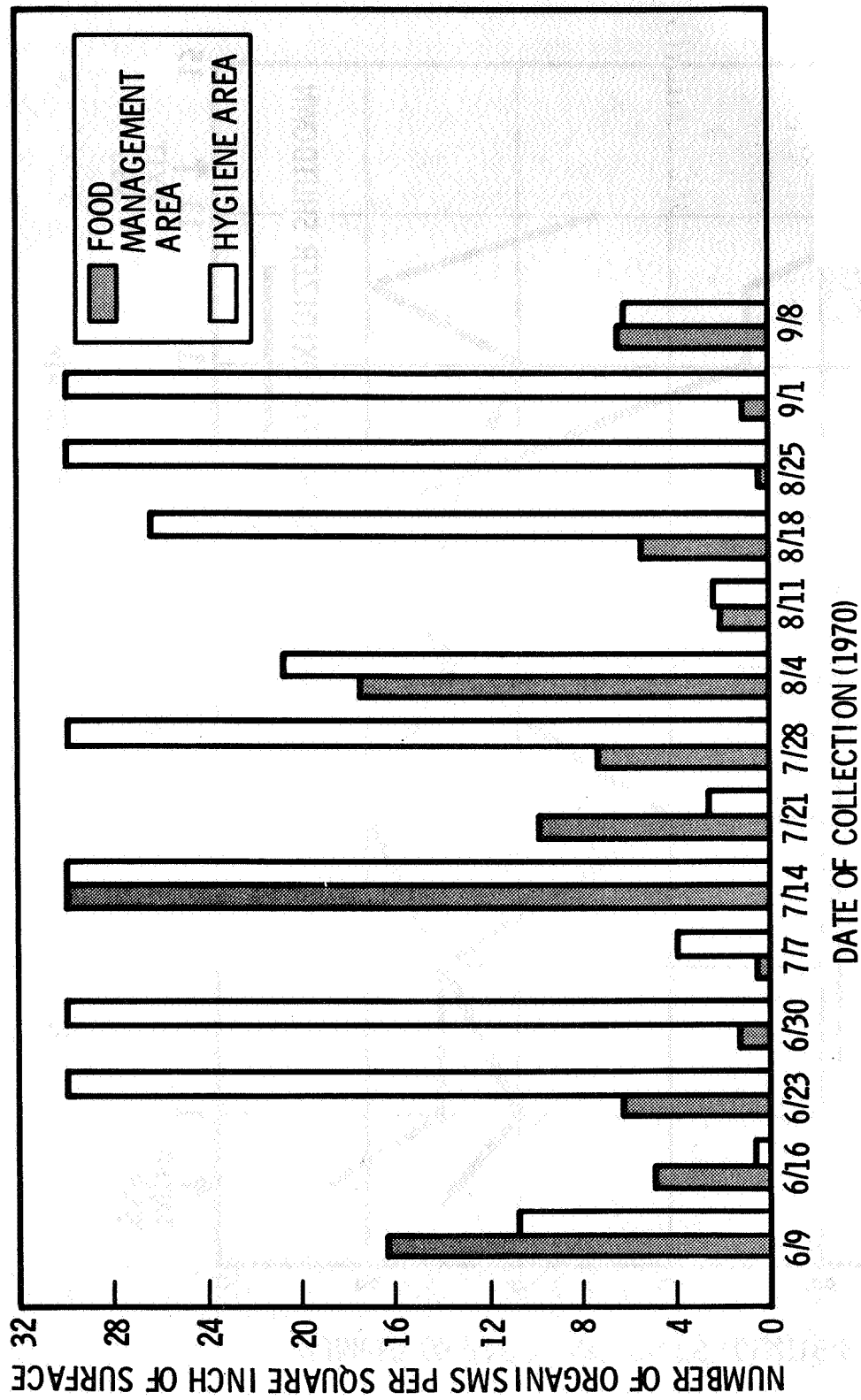


Figure 4. - Bacterial counts from SSS surfaces.

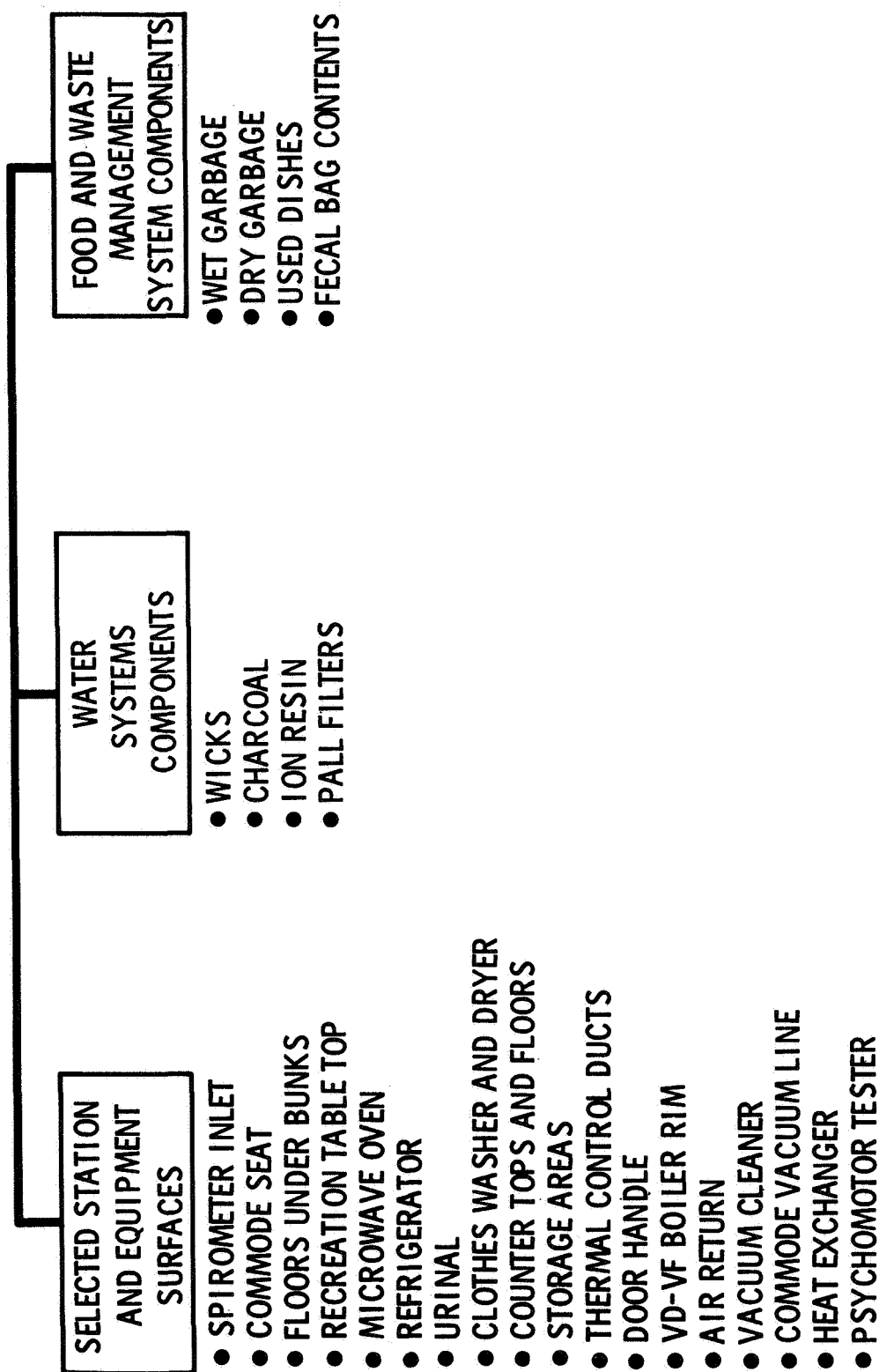


Figure 5.- Post-test sampling for microbial contamination.

NASOPHARYNGEAL STUDIES

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SUMMARY

Before and after the test and weekly during the test, nose and throat swabs from each crewman were cultured for Staphylococcus aureus, beta-hemolytic streptococci, Neisseria meningitidis, Diplococcus pneumoniae and Hemophilus influenzae. Pretest studies indicated that crewman 2 was a permanent nose and throat carrier of S. aureus. On the fourth day of the test S. aureus was recovered from the nasopharynx of the other three crewmembers and was retained by them during the test and in posttest samples. Failure to obtain a phage type or antibiotic sensitivity "marker" for these strains precluded identifying the source of spread of S. aureus within the simulator. Beta-hemolytic streptococci were isolated from the throat of crewman 1 only on the fourth, 60th, and 67th days of the test. Prophylactic erythromycin was administered, and the organism was not recovered during the remainder of the test or from posttest samples. No interpersonal transfer of this organism occurred. Neisseria meningitidis was recovered from the throat of crewman 3 during pretest sampling, throughout the 90-day test, and from posttest samples. This organism was also recovered from the throat of crewman 1 on the 25th and 32d days of the test, but failure to ascertain its specific serological type precluded determining if it had been acquired from crewman 3. N. meningitidis was not recovered from the throat of the other two crewmen. All four crewmen were healthy carriers of Diplococcus pneumoniae, and it was consistently isolated from the throat during the 90-day test. All attempts to recover Hemophilus influenzae failed, and no effort was made to culture this organism after the 53d day of the test. In the 90-day test there was no clinical illness related to the carriage or transfer of potentially pathogenic bacteria. It is recommended that in future simulator tests a series of experiments be performed on the transmission of microbial agents and the effect of the environment on immunoglobulins and other defense responses.

INTRODUCTION

A number of studies of volunteers in test chambers which simulate certain aspects of spaceflight have been made and the results of these tests have been reviewed in the National Academy of Sciences report "Infectious Disease In Manned Spaceflight." (See ref. 1.) Even though the microbiological results have varied from test to test, it does not appear that the closed environments of these simulators significantly affect either the human microflora or the host-parasite relationship. In order to determine, in part, if this pattern would be followed in the 90-day test, the following bacteria of the nasopharynx were selected and cultured on a weekly basis: Staphylococcus aureus,

beta-hemolytic streptococci, Neisseria meningitidis, Diplococcus pneumoniae, and Hemophilus influenzae. Because the health and welfare of the crewmen was of prime consideration in selecting these potentially pathogenic bacteria, the opportunity was also presented for studying the epidemiology of the interpersonal transfer of pathogens.

MATERIALS AND METHODS

Prior to the 90-day manned test, the crewmembers were trained in sterile techniques and the proper procedures for taking nose and throat samples. The four crewmen were divided into two teams; each member of a team was responsible for obtaining swab samples from the other member of the team. Nasal samples were obtained by inserting a sterile, saline-moistened swab about 1/2 inch into either the right or left anterior nostril and swabbing the inner surface three to four times in a circular pattern. A separate swab was used for each nostril.

Throat swabs were taken with the crewman seated, his tongue depressed, and the throat well exposed and illuminated. The swab was rubbed firmly over the back of the throat, both tonsils or tonsillar fossae, and any areas of inflammation or exudation. Care was taken to avoid touching the tongue, lips, or cheek with the swab.

The nasal swabs were streaked onto commercial blood agar and plates of Staphylococcal Medium 110 and incubated for 24 hours at 37° C. Colonies which morphologically resembled Staphylococcus aureus were transferred to Trypticase Soy Broth, incubated for 24 hours at 37° C, and tested for coagulase by mixing equal volumes of broth culture and citrated rabbit plasma diluted 1:5. The tubes were incubated at 37° C for 24 hours and inspected at 4 and 24 hours for clotting. All coagulase positive cultures were sent to Dr. Harry Dalton* for phage typing.

The throat swabs were streaked onto Field's Enrichment Agar for Hemophilus influenzae, Thayer-Martin plates (prewarmed to 37° C) for Neisseria meningitidis and blood agar for beta-hemolytic streptococci and Diplococcus pneumoniae. Field's medium and the blood agar plates were incubated for 24 hours at 37° C; the Thayer-Martin plates were incubated in 5 to 10 percent CO₂. The Field plates were observed for the typical growth of H. influenzae, and the number of colonies and brief colonial description were recorded. N. meningitidis was identified by Gram stain, colony morphology, the oxidase test, sugar fermentations, and serological typing. Optochin disks were used to differentiate between alpha streptococci and D. pneumoniae, and bacitracin disks were used to designate the beta-hemolytic streptococci as probably belonging to Group A. The elapsed time between taking the swab samples and plating on primary isolation media was less than 1 hour.

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RESULTS

"Staphylococcus aureus"

During pretest baseline studies, Staphylococcus aureus was isolated from the nose and throat of crewman 2 only, and not from the other three crewmen. Previous microbiological studies during a 5-day checkout of the space-station simulator strongly indicated that crewman 2 was a permanent carrier of S. aureus. The first swab samples, which were taken 4 days after the crew entered the simulator, indicated that S. aureus was recovered from the throat of crewmen 1 and 3 and from both the nose and throat of crewman 4. (See table I). During the 90-day test, S. aureus was recovered only four times from the throat of crewman 1, consistently from the nose and throat of crewman 2, twice from the nose of crewman 3 and consistently from his throat, and sporadically from the throat of crewman 4 and rather consistently from his nose. It could not be determined if the strains of S. aureus recovered from crewmen 1, 2, and 3 originated from crewman 2 because all attempts to phage-type these isolates were unsuccessful. In addition, antibiotic sensitivity tests failed to show any unusual patterns, as all isolates were sensitive to the major antibiotics. Thus, failure to obtain a phage or antibiotic "marker" for these strains precluded identifying the source of the spread of S. aureus within the simulator. At this time, therefore, it can only be speculated that crewman 2 was the possible source of this organism.

Beta-Hemolytic Streptococci

On the fourth day of the test beta-hemolytic streptococci were isolated from the throat of crewman 1 only. (See table II.) This organism was not recovered during the next 7 weeks from this crewman but was cultured again on the 60th and 67th days of the test. At that time erythromycin was administered as a prophylaxis, and the organism was not recovered during the remainder of the 90-day test or from the posttest samples. It is interesting to note that crewman 1 was also carrying S. aureus in his throat at the time erythromycin was administered, and even though this organism disappeared during antibiotic treatment, it did reappear at the end of the test and in the posttest samples.

"Neisseria meningitidis"

Pretest samples from the crewmen indicated that one crewman (3) was a healthy throat carrier of N. meningitidis. (See table III.) This crewman carried this organism in his throat throughout the 90-day test, and it was also recovered from posttest samples. Neisseria meningitidis was also recovered from the throat of crewman 1 on the 25th and 32d days of the test. However, as type specific typing was not performed, it is difficult to determine if a transfer of N. meningitidis took place between these two crewmen. This organism was not isolated from the other crewmen.

During the pretest studies and the first two weeks of the test, there were relatively few colonies of N. meningitidis on the Thayer-Martin plates from crewman 3. Starting about the 25th day of the test, the number of colonies increased, and on three occasions the growth was confluent. Serological typing revealed that the initial isolates were type C, but on the 60th day of the test, type B as well as type C organisms were isolated. It is possible that this crewman was a carrier of both types of N. meningitidis.

"Diplococcus pneumoniae"

As indicated by the pretest studies, all four crewmen were healthy carriers of D. pneumoniae. (See table IV.) During the course of the 90-day test, D. pneumoniae was consistently isolated from the throat of all crewmen, although on occasions skips occurred in which the organism was not recovered. The cases involving negative cultures were followed by isolation of the organism from the next weekly samples. D. pneumoniae was isolated from all posttest samples 28 days after termination of the test.

"Hemophilus influenzae"

All attempts to recover H. influenzae from the throat of crewmen failed, and no effort was made to culture this organism after the 53d day of the test.

DISCUSSION

There were a number of factors associated with the 90-day test which made it unique so far as the microbiological studies were concerned. Of paramount importance was the fact that a realistic closed environment was obtained, as there was no penetration of the chamber during the test and only a weekly pass-out of biomedical samples through a presterilized autoclave. In all previous tests of space-station simulators, various degrees of penetration of the simulators occurred in order to pass in equipment, spare parts, food, and so forth. Prior to the 90-day manned test the crewmen did not undergo an isolation or quarantine period to permit acute disease to express itself or to exchange flora; therefore, the microbial ecology inside of the chamber consisted of each crewman's own "off-the-street" organisms plus those microorganisms indigenous to the chamber. Another important factor was the rapid processing of samples which permitted the recovery of fastidious organisms such as N. meningitidis. The goal here was to minimize procedural effects on any microbial alterations that might occur during the test. Finally, since the major objective of the 90-day test was the engineering development of life-support subsystems, the crew was exposed to regenerative systems and space-type living conditions. The key features of these systems were: potable water recovered from urine and humidity condensate, oxygen obtained from the reduction of CO₂ and the electrolysis of water, a prototype waste management system based on the "slinger" concept, minimal personal hygiene facilities consisting primarily of body wipes, and an atmosphere of 10 psia (3.1 psia oxygen and 6.9 psia nitrogen). All these factors

and others, either alone or in combination, must be considered as they affect the total microbial ecology inside the chamber.

A number of studies on man in closed environments have been conducted, and the results are summarized in the National Academy of Sciences report, "Infectious Disease in Manned Spaceflight." (See ref. 1.) Based on a literature search, the following two conclusions presented in that report are important as they relate to the microbiological findings of the 90-day test:

"Interpersonal transfer of bacterial pathogens occurred occasionally but did not result in clinical disease, except in the case of outbreaks of respiratory (viral?) disease in submarine crews and in occupants of the underground shelter. In several instances transmission of respiratory and enteric bacteria of potential pathogenicity did not occur even under conditions of extreme crowdedness."

"Although few exceptions occurred which are difficult to evaluate, most of the results reviewed here suggest that the conditions of spaceflight, as simulated by these studies, and for the time intervals tested, will not significantly affect either the microorganisms of the human environment or their hosts to cause a shift in the normal host-parasite equilibrium."

As will be pointed out in the following discussion, the results of the 90-day manned test are in agreement with these two conclusions.

Although it was not possible to "tag" the strain of S. aureus recovered from crewman 2, it is reasonable to assume that the spread of this organism originated from that crewmember. If this is the case, then the subsequent spread, which did not result in clinical disease, is in agreement with the findings of other closed-environment studies (refs. 1 and 2). Beta-hemolytic streptococci were isolated sporadically from crewman 1, and prophylactic erythromycin was administered on the 67th day of the test. There was no evidence of interpersonal transfer of this organism or the development of clinical disease.

The findings of Neisseria meningitidis are of interest because this organism has not been reported from other closed-environment studies. Although one study reported that Neisseria were recovered from four men in a closed system, the species was not identified. (See ref. 3.) In the 90-day test, crewman 3 entered the chamber carrying type C N. meningitidis, maintained it in his throat throughout the test (type B was recovered in the latter stages of the test), and in posttest samples. Again there was no evidence of interpersonal transfer of the organism or the development of clinical disease. All four crewmen were healthy carriers of D. pneumoniae, and clinical disease did not develop.

It has been speculated that the close confinement of man in space-station simulators for prolonged periods of time could represent a serious threat to their health. Some factors influencing these speculations include inadequate filtration and contamination by sneezing, coughing, or touch, since it is well established that transmission of a number of infections is by direct contact

and that the risk of infection is inversely related to distance (ref. 1). Perhaps the most interesting microbiological finding to emerge from the 90-day test is that nothing of serious significance occurred, either to the host flora, or to the host-parasite relationship leading to clinical disease. These findings generally support the observations obtained from other closed-chamber environmental studies (ref. 1). The reasons for these apparently "negative" results are not clear at this time, and the role some factors may play in these simulator studies can only be speculated. In the case of the 90-day test, three organisms were potentially pathogenic, and yet no serious clinical effects occurred. It could be that space simulators are not the hostile environments that many thought they might be, and in fact, the crewmen adapt rather quickly to these new environments. Although these results are encouraging, it must be pointed out, as it was in the National Academy of Sciences report (ref. 1), "...a series of negative results is not a safe basis for extrapolation." It should also be pointed out that the 90-day test concerned itself primarily with aerobic bacteria with minor emphasis on the anaerobes, Mycoplasma, and viruses. Future simulator tests should emphasize these organisms in order to satisfy the requirement that a spacecraft environment will not cause any adverse effects for all groups of microorganisms. Finally, there are still a number of unknown factors associated with actual spaceflight which could markedly alter the normal host-parasite relationship. One of the more important factors is the lack of gravity on (1) the deposition of particles in the respiratory tract and (2) the interpersonal transfer of microorganisms. A continuing research program will be needed to provide answers to these and other questions.

CONCLUDING REMARKS

Before and after the test and weekly during the test, nose and throat swabs from each crewman were cultured for Staphylococcus aureus, beta-hemolytic streptococci, Neisseria meningitidis, Diplococcus pneumoniae, and Hemophilus influenzae. Pretest studies indicated that crewman 2 was a permanent nose and throat carrier of S. aureus. On the fourth day of the test S. aureus was recovered from the nasopharynx of the other three crewmen and was retained by them during the test and in posttest samples. Failure to obtain a phage type or antibiotic sensitivity "marker" for these strains precluded identifying the source of spread of S. aureus within the simulator. Beta-hemolytic streptococci were isolated from the throat of crewman 1 only on the fourth, 60th, and 67th days of the test. Prophylactic erythromycin was administered, and the organism was not recovered during the remainder of the test or from posttest samples. No interpersonal transfer of this organism occurred. Neisseria meningitidis was recovered from the throat of crewman 3 during pretest sampling, throughout the 90-day test, and from posttest samples. This organism was also recovered from the throat of crewman 1 on the 25th and 32d days of the test, but failure to ascertain its specific serological type precluded determining if it had been acquired from crewman 3. N. meningitidis was not recovered from the throat of the other two crewmen. All four crewmen were healthy carriers of Diplococcus pneumoniae, and it was consistently isolated from the throat during the 90-day test. All attempts to recover Hemophilus influenzae failed, and no effort was made to culture this organism after the 53d day of the test. In the 90-day test

there was no clinical illness related to the carriage or transfer of potentially pathogenic bacteria. It is recommended that in future simulator tests a series of experiments be performed on the transmission of microbial agents and the effect of the environment on immunoglobulins and other defense responses.

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3. Riely, Phyllis E.; Geib, Donna; and Shoreinstein, Diane: Determination of the Indigenous Microflora of Men in Controlled Environments. AMRL-TR-66-33, U.S. Air Force, Apr. 1966. (Available from DDC as AD 636 946.)

TABLE I
RECOVERY OF STAPHYLOCOCCUS AUREUS
FROM THE NOSE AND THROAT OF CREWMEN

CREW-MAN	SITE SAMPLED	PRE-TEST DAY	TEST DAY													POST-TEST DAY
		-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
1	NOSE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	+	-	-	-	-	-	-	-	-	+	-	+	+	+
2	NOSE	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3	NOSE	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-
		-	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4	NOSE	-	+	-	+	+	+	-	+	+	+	+	+	+	+	+
		-	+	-	+	+	+	+	-	-	-	+	-	+	-	+

- NOT RECOVERED

+ RECOVERED

TABLE II
RECOVERY OF BETA-HEMOLYTIC STREPTOCOCCI
FROM THE THROAT OF CREWMEN

CREW-MAN	PRE-TEST DAY	TEST DAY													POST-TEST DAY
	-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
1	-	+	-	-	-	-	-	-	-	+	+	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

- NOT RECOVERED

+ RECOVERED

TABLE III
RECOVERY OF NEISSERIA MENINGITIDIS
FROM THE THROAT OF CREWMEN

CREW- MAN	PRE- TEST DAY	TEST DAY													POST- TEST DAY
	-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
1	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	+	+	+	++	+++	+++	++++	++	+++	+++	+++	+++	++++	++++	+
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

- NOT RECOVERED

+ RECOVERED

DEGREE OF GROWTH

10 to 100 +

100 to 300 ++

300 to TNTC +++

CONFLUENT ++++

TABLE IV
RECOVERY OF DIPLOCOCCUS PNEUMONIAE
FROM THE THROAT OF CREWMEN

CREW- MAN	PRE- TEST DAY	TEST DAY													POST- TEST DAY
	-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
1	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+
2	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
3	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+
4	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+

- NOT RECOVERED

+ RECOVERED

CHEMILUMINESCENT BACTERIAL SENSOR

By Judd R. Wilkins
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SUMMARY

The purpose of the chemiluminescent bacterial sensor experiment during the 90-day test was to determine (1) if the sensor could rapidly detect gross contamination of recovered water and (2) the correlation between sensor response and viable counts. The sensor was tested 106 times. The results showed good correlation between a strong sensor response and viable counts on eight occasions. In 60 tests the sensor response was strongly positive, and the plate counts were either negative or below the level of sensor sensitivity or were not performed. Because the sensor responds to living or dead cells, these results suggest that the recovered water may have contained (1) dead bacterial cells, (2) porphyrins leached from cells, or (3) substances unrelated to bacteria which triggered a positive response. With one exception, the correlation between a negative sensor response and plate counts was good on 16 occasions. In 15 tests, quenching of the chemiluminescent reaction occurred. In general, the sensor was able to detect gross contamination rapidly, required minimum crew participation, and was easy to operate. However, further research is needed to determine the nature of those substances in the water which trigger a positive sensor response in the presence of negative or low viable counts; research is also needed to determine the nature of the quenching phenomenon.

INTRODUCTION

During the 90-day test, the chemiluminescent method for rapidly detecting gross contamination of the potable and wash water recovery subsystems was evaluated. The chemiluminescent reaction is that of alkaline luminol (5-amino-2,3-dihydro-1,4-phthalazinedione) with the cytochrome C portion of bacteria in which light is emitted. (See ref. 1.) The amount of light emitted is a function of the number of bacterial cells in the test sample with a sensor sensitivity on the order of 10^3 cells per milliliter. The purpose of the chemiluminescent experiment during the 90-day test was to determine (1) if the sensor could detect gross contamination (greater than 10^3 bacteria per milliliter) in the recovered water and (2) the degree of correlation between sensor response and viable bacterial counts.

MATERIALS AND METHODS

Located inside the space-station simulator was a test chamber attached to a photomultiplier tube which was connected by means of bulkhead connectors to a

photometer and stripchart recorder located outside of the chamber. Operation of the chemiluminescent reaction experiment was performed inside the simulator by one of the crewmembers, who had been trained prior to the 90-day test. All reagents and glassware were stored inside the chamber during the test. With the photometer and recorder warmed up, the test chamber was unscrewed from the adaptor which coupled it to the shutter. After the crewmember had placed the luminol, sodium perborate, and sodium hydroxide reagents in the test chamber, it was reconnected to the adaptor. The shutter was opened, the recorder started, and 0.5 ml of the water sample was injected through the rubber septum. After the emitted light had been recorded, the shutter was closed and the recorder stopped. The test chamber was removed and cleaned in preparation for the next test. Total elapsed time for each test was about 5 minutes. Plate counts were performed by drawing 10 ml of recovered water through a Millipore field kit monitor, adding nutrient broth, and incubating at 37° C for 48 hours. Counts were expressed as the number of bacterial colonies per milliliter and in those cases where overgrowth occurred as "too numerous to count" (TNTC).

DISCUSSION OF RESULTS

During the 90-day test, 14 locations in the potable and wash water recovery subsystems were sampled for a total of 106 tests of the chemiluminescent detector. A comparison of the chemiluminescent results with the 48-hour viable counts obtained with the onboard Millipore field kits are presented in table I. For ease of handling, these data were divided into two parts: those which gave a positive sensor response greater than five units on the photometer and those in which the readings were less than five, specifically, a negative response. Based on previous laboratory experience with this reaction and equipment, the photometer had to register a reading of five or more before it was considered positive. In 14 tests quenching of the reaction occurred. These results plus one case of failure to calibrate the photometer properly are not included in the following data analysis.

Of the 68 onboard tests with a response equal to or greater than five, the correlation between the chemiluminescent detector and the plate counts was good on only eight occasions. As the onboard field-kit procedure did not permit a quantitative expression of the number of bacterial cells in these eight cases of contamination, the counts were recorded as too numerous to count; therefore, the water samples were indicated to be grossly contaminated. At the level of contamination which could be expressed in cells per milliliter, there were 10 cases in which the counts averaged 50/ml, and the sensor response was strongly positive with an average reading of 35.7 on the photometer. There were 33 cases in which the plate counts were negative and the sensor response was positive. There were 17 cases in which plate counts were not performed and the detector response was strongly positive. In reviewing the positive detector results, only a few preliminary statements can be made at this time. In only eight cases was there good correlation between the plate count results and the detector response. As these plate counts were too numerous to count, it can be assumed that the water samples were grossly contaminated. In 43 of 68 positive detector responses, there does not appear to be any correlation between the detector and

plate counts, in 10 cases the number of bacterial cells in the samples was below the sensitivity of the detector, and in 33 cases the plate counts were negative. There is, however, the possibility that a correlation does exist between the detector and plate counts for these 43 cases even though it is not apparent in the data presented in table I. It has been demonstrated by laboratory experience that the chemiluminescent reaction works equally well on living as well as dead bacterial cells. Furthermore, it is also possible that the recovered water entering a storage tank or dispenser contained viable bacterial cells which were killed by the heat (160° F) applied at these points. If this were the case, the low and negative plate count readings could contain dead bacterial cells, which would produce a positive detector response. In the 17 tests in which plate counts were not done it is impossible to determine if the positive responses were caused by living or dead cells or a mixture of these two. It is highly likely, however, that dead bacterial cells or soluble porphyrins derived from these cells were involved in these responses, and studies performed on water samples obtained after the 90-day test tend to support this concept.* Nine samples of water from different sources were analyzed for viable counts, total counts (living and dead cells), and soluble porphyrins. In seven cases it was impossible to differentiate between living and dead counts as quantitative counts were not performed. In two cases the viable counts were negative, in a third case the count was 26 cells/ml, and the total counts were 1.0×10^4 , 2.4×10^5 , and 4.9×10^4 /ml, respectively. Soluble porphyrin studies were performed on eight samples, and the signals were on the average 26 times greater than the distilled water control. There is also the possibility that these "false positive" responses could be caused by substances in the recovered water which were unrelated to bacterial cells but capable of triggering a response in the detector. In either case more research is needed to resolve the nature of these false positive signals and the observed quenching phenomenon.

In the 23 tests with negative detector responses, there was, in general, good agreement between the detector and the plate counts. In one case, the plate counts were too numerous to count, whereas the detector response was less than five. The reasons for this discrepancy are not readily apparent at this time. There appears to be good agreement between the low and negative plate counts and the detector, and in the three cases in which plate counts were not done, it is assumed that water samples did not contain living or dead bacterial cells.

CONCLUDING REMARKS

The purpose of the chemiluminescent bacterial sensor experiment during the 90-day test was to determine (1) if the sensor could rapidly detect gross contamination of recovered water and (2) the correlation between sensor response and viable counts. The sensor was tested 106 times. The results showed good correlation between a strong sensor response and viable counts on eight occasions. In 60 tests the sensor response was strongly positive, and the plate

*Personal communication from F. H. Seubold, Aerojet-General Corp., October, 1970.

counts were either negative or below the level of sensor sensitivity or were not performed. Because the sensor responds to living or dead cells, these results suggest that the recovered water may have contained (1) dead bacterial cells, (2) porphyrins leached from cells, or (3) substances unrelated to bacteria which triggered a positive response. With one exception, the correlation between a negative sensor response and plate counts was good on 16 occasions. In 15 tests, quenching of the chemiluminescent reaction occurred. In general, the sensor was able to detect gross contamination rapidly, required minimum crew participation, and was easy to operate. However, further research is needed to determine the nature of those substances in the water which trigger a positive sensor response in the presence of negative or low viable counts; research is also needed to determine the nature of the quenching phenomenon.

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TABLE I
COMPARISON OF CHEMILUMINESCENT BACTERIAL SENSOR READING
WITH FIELD KIT PLATE COUNTS DURING THE 90-DAY TEST

	SENSOR READING POSITIVE (≥ 5) 68 OF 91 TESTS (75%)				SENSOR READING NEGATIVE (< 5) 23 OF 91 TESTS (25%)			
	PLATE COUNT*				PLATE COUNT*			
	TNTC**	PER mL, AV. 50/mL	NEG.	NOT DONE	TNTC**	PER mL, AV. 112/mL	NEG.	NOT DONE
NUMBER OF TESTS	8	10	33	17	1	3	16	3
PERCENT	12	15	48	25	4	13	70	13
AVERAGE SENSOR READING	29.6	35.7	20.3	72.1	1.0	2.8	2.3	1.3
RANGE OF SENSOR READING	6.5-73.5	5-250	7-60	6-515		1.5-3.0	0.5-4.0	0.5-2.0

* AFTER 48 HOURS INCUBATION AT 37° C.

** TOO NUMEROUS TO COUNT

RADIATION SAFETY REPORT ON THE USE OF $^{238}\text{PuO}_2$ AS A HEAT SOURCE

By A. A. Kelton, Ph. D.

McDonnell Douglas Astronautics Company

SUMMARY

Heat from five capsules containing $^{238}\text{PuO}_2$ in the form of microspheres was used to power a water recovery subsystem in the 90-day manned test of a regenerative life support system in a Space Station Simulator (SSS). Despite 76 manipulations of capsules at a whole-body dose rate of 25 mrem/hr and the existence of a radiation area in a regularly traversed area of the SSS, the average integral exposure for 90 days of confinement was only about 100 mrem, less than 10 percent of the normally allowed dose. Simple, manageable handling tools and straightforward procedures prevented any thermal injuries and deterred excessive exposure of the extremities to ionizing radiation. No discernible damage was sustained by any of the capsules, and no release of radioactive contamination could be detected. Several improvements in devices and procedures for the radiological safety of radioisotope power applications in manned spacecraft were identified as a direct result of studies in the SSS. These studies indicate that current tendencies toward excessive protective measures may be unnecessarily impeding application of thermal power from plutonium-238 to such space systems as Skylab and Space Station.

INTRODUCTION

One of the record events accomplished during the 90-day test of an SSS was the use of radioisotope heat to power a water recovery subsystem for four crewmen within a sealed environment. This part of the regenerative life support system consisted of a vacuum distillation-vapor filtration (VD-VF) unit heated by 340 watts from five encapsulated radioisotope heat sources. These were fueled by about 10,000 curies of $^{238}\text{PuO}_2$ in the form of microspheres.

A major obstacle to general acceptance of radioisotope power as a simple and dependable source of thermal energy within manned spacecraft has been uncertainty about onboard radiological safety problems, such as shielding, placement of capsules, and radiation exposure of the crew during handling of the capsules and continuous work within a radiation environment. Since thermal energy can constitute over one half of the basic power requirements of a manned spacecraft (e.g., Skylab) the use of radioisotope heat could significantly decrease electrical power requirements and/or increase mission capability. The 90-day manned test provided a unique opportunity to safely evaluate radiological hazards under simulated conditions.

The radiological safety program for the 90-day test dealt with two distinct hazards. The most prominent hazard consisted of direct exposure of personnel to ionizing radiations emanating from the capsules. The second hazard derived from the very remote possibility that a capsule might accidentally leak radioactive contamination. Trained personnel and special equipment, facilities, and procedures were employed to protect the health of the crewmen and to evaluate the significance of these radiological hazards so that similar radioisotope-fueled devices might be safely and confidently employed in a future Skylab or Space Station.

RESULTS

Evaluation of External Radiation Hazards

The external hazard posed by the radioisotope heat source capsules consisted of neutrons and gamma radiations. Neutrons, the most prevalent and hazardous radiation, emanated from spontaneous fission of ^{238}Pu and (α , n) reactions within the $^{238}\text{PuO}_2$. Gamma radiations resulted from the radioactive decay of daughter products and impurities and constituted about 10 percent of the dose. A 73-watt capsule produced a dose rate slightly greater than 5 mrem/hr at 1 meter and about 25 mrem/hr to the eyes and whole body at convenient handling distances. Such dose rates necessitated shielding the VD-VF unit, consideration of the location of the VD-VF unit and storage container (chill box) within the SSS, and thorough analysis of handling operations.

The interior layout of the SSS with respect to the radiation areas is shown in fig. 1. As indicated, the VD-VF unit was located in the equipment and storage room. When the VD-VF unit was not in operation, the capsules were stored in water contained in a chill box located across the aisle from the VD-VF unit. The water was used to cool and shield the capsules.

A movable, U-shaped tank containing water was constructed to shadow-shield the VD-VF unit. Stationary water tanks above, below, and behind the unit were also a part of the shadow shield. A sketch of the shielding arrangement is shown in fig. 2. Calculations indicated that at least a 10-in. thickness of water in the shield would be required for uncontrolled access to the area (8-hour working day). Due to the volume occupied by the VD-VF unit and its thermal insulation, the mass and dimensions of such a shield would have been incompatible with easy access to the VD-VF unit, space available in the equipment and storage room, the actual time spent by the crew in the vicinity of the unit, and the general objectives of the program. As a compromise, shielding guidelines were established to prevent exposure of any major portion of the body to a dose rate in excess of 5 mrem/hr for the majority of activities and normal traffic within the equipment and storage room. Shielding was such that during normal operations of the VD-VF unit no area was accessible to personnel that would result in exposure of a major portion of the body to a dose rate in excess of 100 mrem/hr. When the layout of the equipment and storage room and the schedule of crew activities were examined, the usual activities and traffic were at distances greater than 1 meter from the outer

surface of the shield. Calculations for this condition indicated that a 4-in. thickness of water plus the water always present in the VD-VF unit would shield to a dose rate of about 25 mrem/hr at the surface of the shield and 2.8 mrem/hr at 1 meter from the surface.

Before the shield was constructed, the conditions of exposure were analyzed to assure that no crewman would be knowingly exposed to an integral dose that would exceed the allowances given in the radiation protection guide (table 1).

The dose rates were calculated for various locations within the Space Station Simulator. Using these data, the maximum integral dose to a crewman was tabulated as shown in table 2 according to the schedule of crew activities and the maximum dose rate for the location of that activity in the SSS. From table 2, the integral dose for 90 days was expected to be less than the generally allowed dose 1.25 rem and well within the 3 rem that could be permitted for 3 months of radiation work. The actual dose rates were measured with neutron and gamma survey meters before the beginning of the 90-day test. These dose rates are indicated in figures 2 and 3 and essentially agreed with the calculated dose rates.

Personnel dosimetry during the 5-day checkout and the 90-day test consisted of film badges and pocket dosimeters. The film badges were the legal record of the radiation exposure of the crewmen. Each crewman wore two film badges and two pocket dosimeters. One film badge contained both neutron and gamma-sensitive films. During the 90-day test, a supply of film packets was stored in the cabinet in the living quarters most distant from the radiation area. Each week, the crew changed film packets in these badges and sent the exposed packets, plus a control packet, out of the SSS via the weekly pass-out of samples. The other film badge contained only a gamma-sensitive film and was retained for the full 90 days. The film packets were specially supplied, developed, and evaluated for the recorded dose by the Office of Environmental Health at the University of California at Los Angeles. Each crewman was also issued a set of direct-reading pocket dosimeters, one sensitive to gamma and the other sensitive to neutron and gamma radiation. The total accumulated dose indicated on each dosimeter was recorded daily. The pocket dosimeters were only used to indicate any excessive daily exposure. At low doses (<2 divisions/200 scale divisions), these dosimeters were prone to artifact and large inaccuracies in use and interpretation.

The film badge results are shown in table 3. Three of the four crewmen received total doses lower than permitted for the general population. The fourth crewman received only 25 percent of the maximum expected dose, 14 percent of the generally allowed dose, and about 6 percent of the maximum permissible dose for 13 weeks. The low levels of gamma radiation were not detectable on either the weekly or 90-day film packets. The pocket dosimeter readings were considered to be unreliable due mostly to large errors in interpreting the readings and lack of agreement between the neutron and gamma dosimeters of each set.

In general, both the film badge results and the pocket dosimeters indicated that handling of the capsules constituted the greatest source of

radiation exposure. The record of capsule handling is shown in table 4. The capsules were exchanged between the VD-VF unit and the chill box on 14 occasions which resulted in 76 manipulations of individual capsules. By examining the frequency that each crewman handled the capsules and the differences in their recorded radiation doses, the average dose to a crewman or a handling operation can be estimated. Figure 4 illustrates the technique of handling and the radiation environment surrounding the capsule. The capsule was held in about the same geometry throughout each transfer, so that the average dose can be approximated at 1 to 3 mrem. The average transfer time including a smear test was estimated at 2 to 6 minutes.

Evaluation of Radioactive Contamination Hazards

Problems of control of radioactive contamination were not anticipated. First, the capsules were designed and tested to prevent release of any radioactive materials for all credible accidents during shipment of the capsules or testing of the VD-VF unit. Second, special procedures and equipment were used to prevent credible accidents. Third, the chemical and physical form of the $^{238}\text{PuO}_2$ microspheres minimized the danger to health and property from contamination in the unlikely event of capsule leakage or rupture. Nevertheless, a rigorous program of control was conducted in the event of accidental release of radioactive material from the capsules. The program emphasized the detection and containment of radioactivity and emergency procedures to minimize any contamination of personnel or property.

A preliminary accident analysis gave the following results. The total mass of plutonium-238 was less than 10 percent of the minimum critical mass reflected. Further, the storage and utilization of the capsules in water lessened the potential for criticality, which was clearly impossible. The worst credible accident would have occurred if the double encapsulation of a heat source were ruptured and the contents spilled onto the floor of the closed SSS. Approximations indicated that if an air monitor warning were given within 30 sec, the crew could probably have escaped from the SSS without overexposure to ^{238}Pu . The regulations which limit internal exposure to $^{238}\text{PuO}_2$ are shown in table 5. The critical organ was considered to be the lung and only the limits for the insoluble form are relevant. Procedures were adopted to prevent such an accident or, indeed, any damage to the capsules.

A more credible accident would have been the leakage of radioactivity from a capsule resulting from mechanical or chemical damage or manufacturing defect. The leakage would have been augmented by helium buildup in the capsule and might have been a slow seepage or a rapid leak (puff) with the helium expanding and diffusing through the microsphere fuel. No data are available for a reliable evaluation of the consequences of capsule leakage. Using several approximations, a slow leak was not expected to yield a maximum permissible concentration (MPC) of $10^{-11} \mu\text{Ci}/\text{cm}^3$ for continuous exposure of the lung. However, a puff release might produce a concentration of $^{238}\text{PuO}_2$ in air that would exceed acceptable limits by factors as large as 10^2 to 10^3 . Such concentrations could result in a maximum permissible lung burden (MPLB) for a crewman within 1 to 10 hours. Another credible, but

unlikely, accident could have resulted from overheating of a capsule. If the capsule were thermally insulated until its temperature exceeded $\sim 2,000^{\circ}\text{F}$ or $\sim 1300^{\circ}\text{K}$, the capsule might rupture because of internal helium pressure augmented by other mechanical stresses. Calculations showed that at such temperatures the volatilization of $^{238}\text{PuO}_2$ could release radioactivity at the rate of $\sim 13 \mu\text{Ci/hr}$. Such a release rate within the SSS would exceed the MPC for ^{238}Pu within 1 minute and could result in a MPLB within about 1 hour. However, in view of the many precautions instituted, no conceivable accident could have resulted in a capsule overheating or even reaching its design operating temperature.

The procedures for detecting any release of radioactivity included air monitoring, smear analysis, radiation survey, and water analysis. The air in the vicinity of the capsules was continuously monitored for α -emitting contamination by an air monitor equipped with an audible and visual alarm. During every handling operation, the entire surface of each capsule was wiped with a dry cloth. All smears were checked for α -emitting contamination with an α -survey meter and occasionally checked with an isotope analysis unit. Handling devices, personnel, clothing, and any surfaces coming in contact with the capsules were surveyed for α -emitting contamination. Prior to human consumption, samples of reclaimed water from the VD-VF unit were monitored for radioactive contamination by survey of the dried samples and analysis in the isotope analysis unit.

The air monitor filter was changed daily, and the air monitor was checked for performance and calibrated with a ^{239}Pu α -standard. The α -standard was also used to calibrate the α -survey meter before use and the isotope analysis unit. Emergency and contingency procedures were adopted and were to be instituted whenever predetermined levels of radioactivity could be detected in the air or water or by a smear test.

The results of continuous air monitoring are shown in figures 5 and 6. The daily reading of the air monitor ratemeter decreased rapidly during the first few days corresponding to the rapid decay of radon after the SSS was closed. Based upon the MPC of ^{238}Pu in air for continuous exposure and the sampling rate and counting efficiency for the air monitor, contingency conditions were established for an alarm at 300 cpm. Emergency procedures were required to prevent inhalation of an MPLB when a time of less than 5 minutes elapsed between an alarm at 300 cpm and an alarm at 1,000 cpm. The air monitor failed on several occasions. Two false air monitor alarms occurred, once during the 5-day trial and once during the 90-day test. In both cases the crew established within 0.5 to 1 minute that the alarm did not result from radioactivity but instrument malfunction. A short circuit in the ratemeter caused the first alarm, while a noisy photomultiplier tube caused the second alarm. Batteries in the scintillation probe had to be replaced twice during the 90-day test. Finally, the constant-flow air pump failed on the 88th day and was replaced with an air pump normally used for bacteriological sampling. Measurement for any radioactivity on the daily air filters was also performed with the isotope analysis unit. From fig. 6, the early results were unusually variable considering the stability of the instrument. Further, the value of a particular measurement was found to decrease as the time after removal of the filter increased. Preliminary tests by the crew suggested that

the aberrant measurements were caused by a static charge on the filter which neutralized the charge on the quartz fiber electroscope (isotope analysis unit). This conclusion was verified by experiments following the 90-day test. The difficulty was corrected on day 57 by allowing an extra day to elapse before measurement. Using the isotope analysis unit, the contingency level for air filters corresponded to the time for the quartz fiber to move 20 scale divisions in less than 45 minutes or at a rate of 27 units/hr. An emergency condition prevailed when a deflection of 20 scale divisions occurred in less than 50 sec.

The results of surveys for radioactive contamination are shown in table 4. No α -emitting contamination could be detected above the background radiation levels normally indicated by the α -survey meter. One false indication of radioactivity occurred following a smear test on capsule BT-38. This smear was immediately checked on the air-monitor probe and with the isotope analysis unit. Both revealed no radioactivity. The false alarm was traced to a noisy photomultiplier tube which was replaced.

Measurements of water samples and some smear samples with the isotope analysis unit are shown in fig. 7. None of these measurements were significantly different than background measurements. The contingency levels for gross $\beta\gamma$ activity were a rate of ≥ 10 div/hr for a smear sample and ≥ 5 div/hr for a dried 20-ml water sample. A MPC of ^{238}Pu in the drinking water would have given a deflection rate of about 300 div/hr for a dried 20-ml sample. An emergency level corresponded to a deflection of 20 scale divisions in less than 6 minutes for a smear sample and less than 20 sec for a water sample contaminated with ^{238}Pu .

DISCUSSION

The 90-day manned test of a Space Station Simulator has resulted in data and assessments that will be useful in the realistic evaluation of radiological safety problems arising from the potential use of plutonium-238 heat sources in future life support systems of manned spacecraft. In particular, the questions of difficulties and hazards in handling of the heat source capsules and the dose resulting from crew activities in the presence of an open radiation area can now be addressed with the perspective of experience.

Some of the results suggest definite answers to such questions. Thus, the heat source capsules were handled in 76 separate manipulations without incident or difficulty. Simple and manageable handling tools and practical procedures prevented any thermal injuries and deterred excessive exposure of the extremities to ionizing radiation. No discernible damage was sustained by any of the capsules and no release of radioactive contamination could be detected. Despite the existence of an open radiation area in a regularly traversed section of the SSS, the average exposure of the crewmen was less than 10 percent of the normally allowable dose, within the level permitted for the general population, and only 13 percent of the maximum predicted dose. Such observations should counteract prevalent tendencies to overshield, over-complicate, and overprice in those space programs that seek to employ the advantages of radioisotope power.

Perhaps the most useful result of this test will be the development of a methodology to more accurately predict the dose to the crew of a Skylab or Space Station as a result of the use of radioisotope heat in life support subsystems. Personnel dosimetry indicated that total dose of the test was much less than that estimated. The overestimate was caused by the inclusion of safety factors in the calculations of dose from handling, shielding, and the distance and time associated with each scheduled crew activity. Detailed data are now available regarding actual crew movements within the Space Station Simulator. The crew work schedule was planned in extreme detail and meticulously monitored throughout the test. The location of each crewman was determined every 2-1/2 minutes during substantial portions of the test. Following computer reduction of these data, summaries of the locations and durations of the tasks can be compared with the planned schedule for the crew. Once integrated with the other test results, this information will yield more realistic safety factors for future use in optimizing the shielding weight and the location of radioisotope sources in relation to expected crew activities.

The 90-day test also indicated that a definite spacecraft requirement exists for the development of instruments, devices, and procedures to detect and contain radioactivity. Although extremely remote, the possibility of a radioactive contamination hazard must be neutralized in the closed environment of a manned spacecraft. Approximate calculations indicated that damage resulting in leakage from one or more of the capsules or overheating with capsule rupture could release airborne radioactivity that would rapidly exceed the maximum permissible concentration in air and result in a maximum permissible lung burden within minutes. However, the magnitude and characteristics of any release of radioactivity would need to be experimentally determined to realistically design for the hazard. Nevertheless, design requirements, such as the inclusion of a small, lightweight containment vessel with air monitoring, or a heat pipe to remove excessive heat, could be adopted that would greatly reduce the significance and hazards of these remote possibilities and provide the opportunity for remedial action. In particular, the 90-day test revealed the need for several improvements in radioactivity monitoring instruments. Some of the features that should be included in the design of the air monitor and survey meter are

- A. An electronic means of discriminating between an alarm caused by instrument malfunction and one resulting from radioactivity.
- B. Warning indicators of radioactivity level, radioactivity release rate (air monitor), and instrument failure.
- C. Built-in radioactive calibration sources, electronic calibration, and elective indications of critical voltages.
- D. Interchangeable ratemeters, detector assemblies, and some electronic components.

Although the development and test of such equipment and methods are an essential adjunct to use of radioisotope power, they involve existing capability and technology and should require only a minor effort and expense. Most of

the design improvements suggested in this report were identified as a direct result of the monitoring experience in the Space Station Simulator.

An important contribution of the 90-day test was proof of the value of simulated testing of procedures and instrumentation designed for radiological safety in manned space systems. Thus, before final acceptance of instrument designs and procedural concepts for radiological safety in a future Skylab or Space Station, prototypes should be evaluated in a manned test of a Space Station Simulator. This should include an evaluation of the methodology used to predict crew dose and determine shielding based on location of the radioisotope heat sources and crew activities. The handling characteristics of flight-rated radioisotope heat sources and the long-term operating characteristics of these sources in life support subsystems should be determined. The performance of space flight prototypes of the air monitor, survey meter, and personnel dosimetry should be substantiated. The procedures, instrumentation and crew performance should be further evaluated under the duress of simulated credible accidents. The experience gained by such testing is certain to establish confidence and perspective not attainable by speculation.

In conclusion, the use of $^{238}\text{PuO}_2$ fueled heat sources in a 90-day manned test of a life support system in the Space Station Simulator represented a significant advancement in the acceptability of radioisotope power sources for use within manned space stations.

REFERENCES

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Plutonium-238 Isotopic Fuel Form Data Sheets. MLM 1564, Monsanto Research Corp., 1968.
2. Anon.: Report of Committee II on Permissible Dose for Internal Radiation.
ICRP Publ. 2, Pergamon Press, Inc., 1959.

TABLE 1.- FEDERAL RADIATION COUNCIL RADIATION PROTECTION GUIDE*

TYPE OF EXPOSURE	CONDITION	DOSE (REM)
RADIATION WORKER:		
(A) WHOLE BODY, HEAD AND TRUNK, ACTIVE BLOOD-FORMING ORGANS, GONADS OR LENS OF EYE	ACCUMULATED DOSE	5 TIMES THE NUMBER OF YEARS BEYOND AGE 18
	13 WEEKS	3
(B) SKIN OF WHOLE BODY AND THYROID	YEAR	30
	13 WEEKS	10
(C) HANDS AND FOREARMS, FEET AND ANKLES	YEAR	75
	13 WEEKS	25
(D) BONE	BODY BURDEN	0.1 MICROGRAM OF RADIUM-226 OR ITS BIOLOGICAL EQUIVALENT
(E) OTHER ORGANS	YEAR	15
	13 WEEKS	5
POPULATION:		
(A) INDIVIDUAL	YEAR	0.5 (WHOLE BODY)
(B) AVERAGE	30 YEAR	5 (GONADS)

*FROM FEDERAL REGISTER, 18 MAY 1960

TABLE 2.- MAXIMUM INTEGRAL DOSE FOR THE 90-DAY TEST

CREWMAN'S ACTIVITY	MAXIMUM INTEGRAL DOSE (MREM)*	CREWMAN'S ACTIVITY	MAXIMUM INTEGRAL DOSE (MREM)*
LRC TESTER	9.4	MAINTENANCE	26.5
EATING	24.0	LAUNDRY	3.8
SLEEPING	72.0	CABIN CLEANING	8.0
EXERCISE	57.0	LSS MONITORING	2.2
RECREATION	178.0	PASS-OUT	2.0
BODY HYGIENE	90.0	QUESTIONNAIRE	0.8
WASTE MANAGEMENT	45.0	MICROBIOLOGICAL	1.5
COMMUNICATIONS	55.0	WASTE WATER FILTER	
PHOTOGRAPHY	8.9	CHANGE	1.5
MEDICAL DATA	4.4	PSYCHIATRIC INTERVIEW	0.2
SAMPLE COLLECTION	16.0	SERUM SAMPLE	0.6
MICROBIAL CULTURE	8.7	PHARYNGEAL	0.3
DATA MANAGEMENT	18.0	UNSCHEDULED ACTIVITIES	34.0
MEDICAL INTERVIEW	16.5	VD-VF CHANGEVER	120.0
		TOTAL	804.3
INTEGRAL DOSE FOR ALL ACTIVITIES DURING THE 90-DAY TEST IS APPROXIMATELY			800 MREM

*CALCULATED FROM PRELIMINARY ONBOARD TIME DEMANDS WITH THE ASSUMPTION OF A FOUR-INCH SHIELD OF WATER AROUND THE VD-VF UNIT.

TABLE 3.- PERSONNEL DOSIMETRY FILM BADGE READINGS

FILM BADGE SEQUENCE, WEEK (5-DAY TEST)	INDIVIDUAL DOSE (MREM/WEEK)							
	CREWMAN NO. 1		CREWMAN NO. 2		CREWMAN NO. 3		CREWMAN NO. 4	
	$\beta\gamma$	n	$\beta\gamma$	n	$\beta\gamma$	n	$\beta\gamma$	n
	0	0	0	0	0	0	0	0
1	0	0	0	30	0	20	0	20*
2	0	10	0	0	0	40	0	10
3	0	0	0	10	0	10*	0	10
4	0	60	0	0	0	0	0	0
5	0	30	0	40	0	30	0	10
6	0	10	0	20	0	10	0	0
7	0	20	0	0	0	0	0	10
8	0	0	0	10	0	20	0	0
9	0	10	0	0	0	10	0	20
10	0	10	0	0	0	0	0	0
11	0	0	0	10	0	0	0	0
12	0	0	0	0	0	60	0	30
13	0	20	0	10	0	10	0	10
SUBTOTAL	0	170	0	130	0	210	0	120
TOTAL DOSE, MREM	170		130		210		120	
CORRECTED TOTAL DOSE, MREM**	110		60		170		80	

*HIGH ENERGY EVENT (STAR), NO EXPOSURE CALCULATED.

**THE TOTAL DOSE IS THE SUMMATION OF THE WEEKLY DOSE MINUS BACKGROUND, $\Sigma(n - nbkg)$ WHERE n IS THE NUMBER OF NEUTRON TRACKS, WHILE THE CORRECTED TOTAL DOSE IS THE SUMMATION OF THE TOTAL NEUTRON TRACKS MINUS TOTAL BACKGROUND NEUTRON TRACKS, $\Sigma n - \Sigma nbkg$. THE CORRECTED DOSE THUS ACCOUNTS FOR ALL OF THE NEUTRON TRACKS AND IS NOT AS AFFECTED BY THE POOR STATISTICS OF THE WEEKLY TOTAL.

NOTE: FILM BADGES ISSUED FOR THE 13-WEEK PERIOD SHOWED GENERAL DARKENING COMPARED TO CONTROL FILMS ISSUED AT THE SAME TIME. SINCE THE DARKENING WAS UNIFORM OVER THE WHOLE FILM, IT WAS PROBABLY NOT DUE TO RADIATION EXPOSURE, BUT DUE INSTEAD TO DIFFERENCES IN TEMPERATURE AND/OR HUMIDITY DURING THE 90-DAY TEST.

TABLE 4.- RECORD OF CAPSULE HANDLING AND SURVEYS
FOR RADIOACTIVE CONTAMINATION

DATE	ALPHA EMITTING CONTAMINATION FROM EACH CAPSULE						CAPSULES TRANSFERRED		REASON FOR TRANSFER
	BT-2	BT-15	BT-16	BT-21	BT-38		FROM	TO	
6-14	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF*	STARTUP OF VD-VF I
7-9	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	URINE SOLID ACCUMULATION
7-9	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF	STARTUP OF VD-VF II
7-10	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	FLOODED CATALYST
7-13	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF	STARTUP OF VD-VF
7-13	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	FLOODED CATALYST
7-16	BKG	BKG	BKG	BKG	ALARM**		CHILL BOX	VD-VF*	STARTUP OF VD-VF
7-21	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	STERILIZATION REQUIRED
7-22	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF	STARTUP OF VD-VF
7-27	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	FLOODED CATALYST
8-3	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF	STARTUP OF VD-VF
8-17	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	STERILIZATION REQUIRED
8-17	BKG	BKG	BKG	BKG	BKG		CHILL BOX	VD-VF	STARTUP OF VD-VF
9-1	BKG	BKG	BKG	BKG	BKG		VD-VF	CHILL BOX	ACCUMULATION OF URINE SOLIDS, FINAL SHUTDOWN OF VD-VF II

BKG = NO RADIOACTIVE CONTAMINATION COULD BE DETECTED ABOVE BACKGROUND RADIATION LEVELS INDICATED BY THE ALPHA SURVEY METER.

* = ADDITIONAL TRANSFERS OF INDIVIDUAL CAPSULES RESULTED IN SIX ADDITIONAL MANIPULATIONS WITH VD-VF IN EXTENDED POSITION: A 73W CAPSULE WAS USED FOR RAPID HEATING OF THE CATALYST AND WAS LATER EXCHANGED FOR THE 48W CAPSULE IN THE EVAPORATOR UNIT.

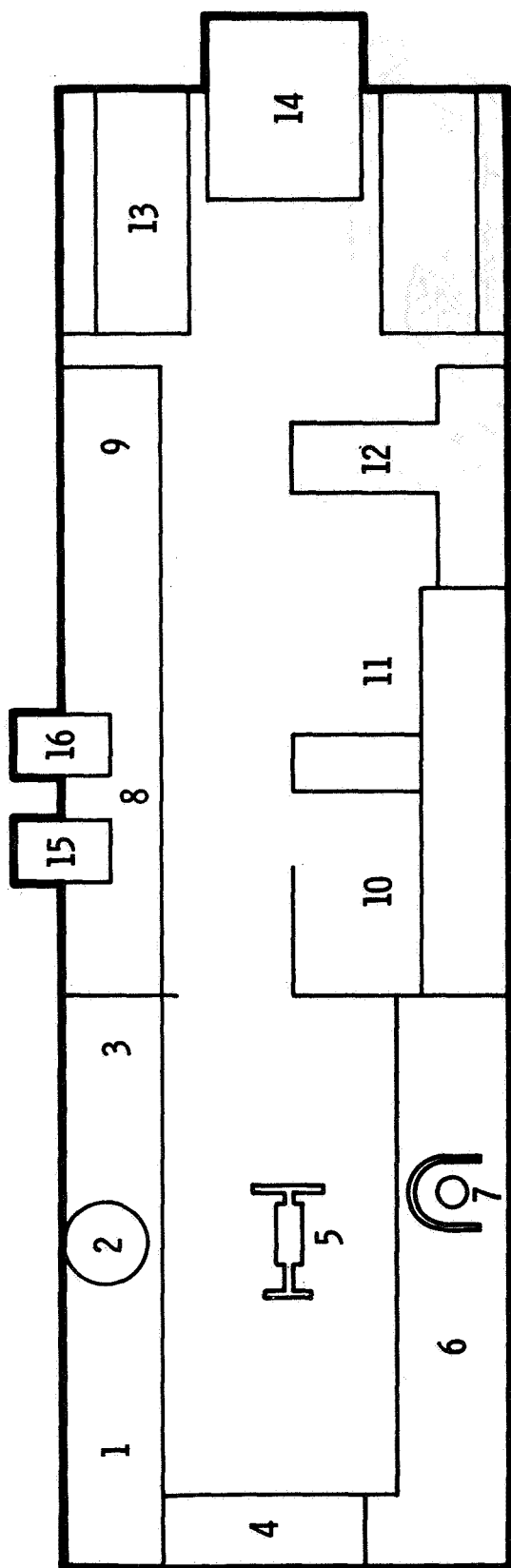
** = FALSE INDICATION OF RADIOACTIVE CONTAMINATION: SMEAR IMMEDIATELY CHECKED ON AIR-MONITOR ALPHA PROBE AND ISOTOPE ANALYSIS UNIT, BOTH REVEALED NO CONTAMINATION; FALSE ALARM TRACED TO FAULTY PM TUBE.

TABLE 5.- RADIOBIOLOGICAL TOLERANCES OF ^{238}Pu

[From reference 1]

RADIONUCLIDE AND TYPE OF DECAY	LOCATION OF REFERENCE	PERMISSIBLE BURDEN IN TOTAL BODY $q(\mu\text{Ci})$	RADIATION PROTECTION GUIDES			
			FOR A 40-HR WEEK (RPG) WATER $\mu\text{Ci cm}^{-3}$	(RPG) AIR $\mu\text{Ci cm}^{-3}$	FOR A 168-HR WEEK ^c (RPG) WATER $\mu\text{Ci cm}^{-3}$	(RPG) AIR $\mu\text{Ci cm}^{-3}$
$^{238}\text{Pu}(\alpha, \gamma)$	BONE	0.04	10 ⁻⁴	2x10 ⁻¹²	5x10 ⁻⁵	7x10 ⁻¹³
	LIVER	0.2	6x10 ⁻⁴	8x10 ⁻¹²	2x10 ⁻⁴	3x10 ⁻¹³
	KIDNEY	0.3	8x10 ⁻⁴	10 ⁻¹¹	3x10 ⁻⁴	4x10 ⁻¹³
	GI(LLI) ^a	...	8x10 ⁻⁴	2x10 ⁻⁷	3x10 ⁻⁴	6x10 ⁻⁸
	TOTAL BODY	0.3	10 ⁻³	10 ⁻¹¹	4x10 ⁻⁴	5x10 ⁻¹²
(INSOL.)	LUNG	b	...	3x10 ⁻¹¹	...	10 ⁻¹¹
	GI(LLI)	...	8x10 ⁻⁴	10 ⁻⁷	3x10 ⁻⁴	5x10 ⁻⁸

^aTHE ABBREVIATIONS GI AND LLI REFER TO GASTROINTESTINAL TRACT AND LOWER LARGE INTESTINE, RESPECTIVELY.^bCURRENTLY ACCEPTED LUNG BURDEN IS 0.016 μCi . THIS VALUE WAS CALCULATED BY THE STANDARD FORMULA AS GIVEN BY ICRP COMMITTEE II ON PERMISSIBLE DOSE FOR STANDARD RADIATION (1959). (REF 2).^cUSE 1/10 OF THESE VALUES FOR OFF-SITE ENVIRONMENTAL LEVELS.



LEGEND

- | | |
|----------------------------|---|
| 1. EXPERIMENTS/STORAGE | 9. COUNTER/STORAGE |
| 2. CHILL BOX | 10. WASTE MANAGEMENT/
PERSONAL HYGIENE/STORAGE |
| 3. MAINTENANCE/SPARE PARTS | 11. FOOD PREPARATION/STORAGE |
| 4. COMMAND STATION | 12. DINING/RECREATION |
| 5. ERGOMETER | 13. BUNKS |
| 6. LIFE SUPPORT EQUIPMENT | 14. AIRLOCK |
| 7. VD-VF UNIT | 15. PASS-THROUGH AIRLOCK |
| 8. ONBOARD LAB/STORAGE | 16. AUTOCLAVE |

Figure 1.- Simplified interior layout of space station simulator.

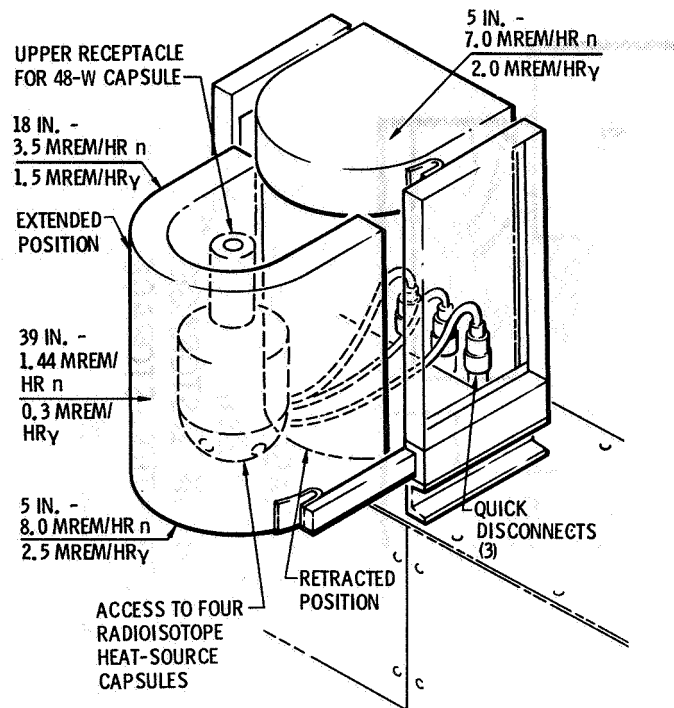


Figure 2.- Radiation survey near VD-VF unit with retracted shield.

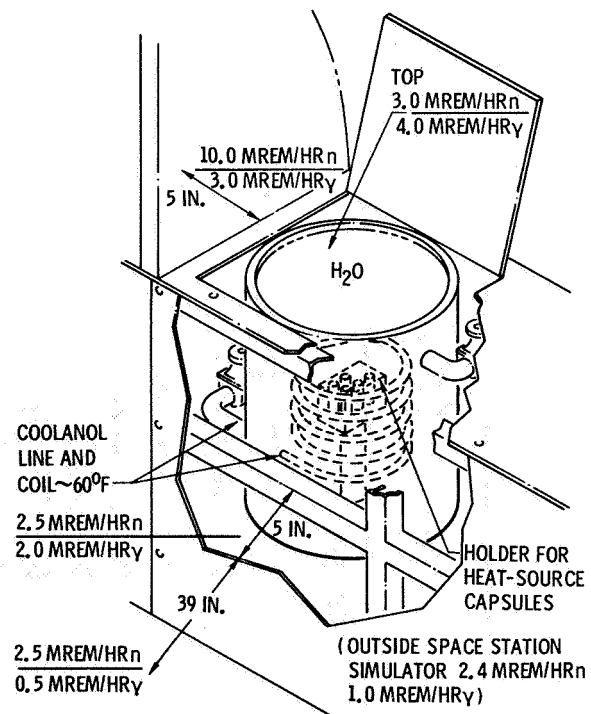
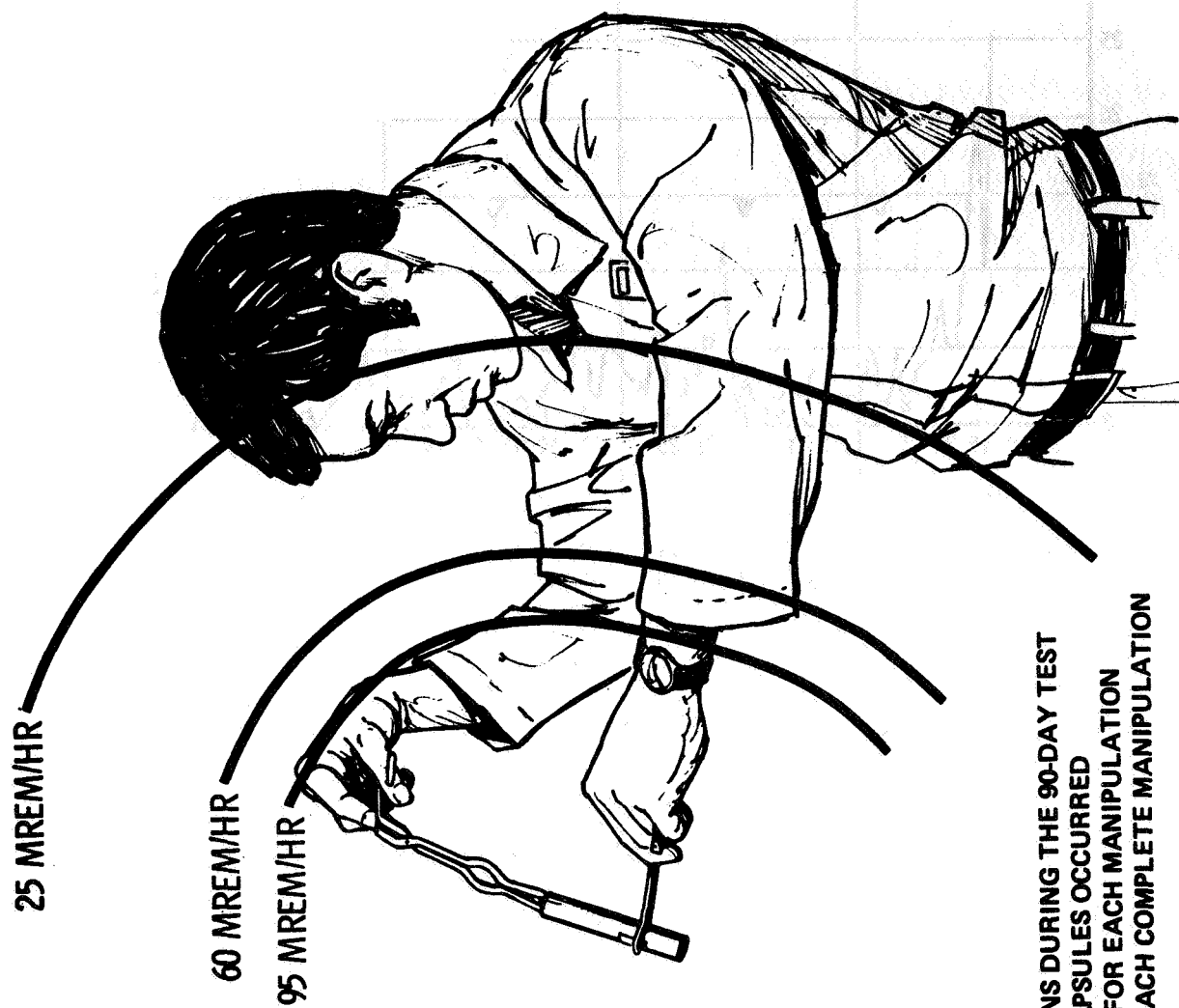


Figure 3.- Radiation survey near isotope storage container in SSS (chill box).



HANDLING AND EXPOSURE DATA

1. 14 DIFFERENT HANDLING OPERATIONS DURING THE 90-DAY TEST
2. 76 SEPARATE MANIPULATIONS OF CAPSULES OCCURRED
3. WHOLE-BODY DOSE OF 1 TO 3 MREM FOR EACH MANIPULATION
4. 2-1/2 TO 7 MINUTES REQUIRED FOR EACH COMPLETE MANIPULATION

Figure 4.- Exposure to ionizing radiation during handling of Pu-238 capsules.

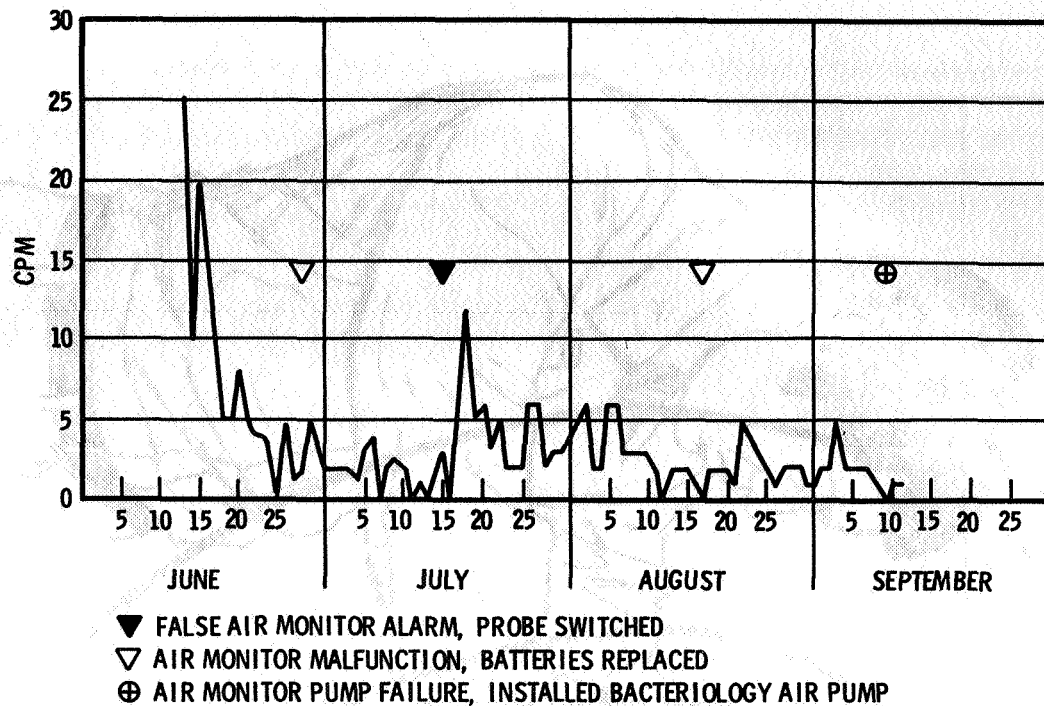
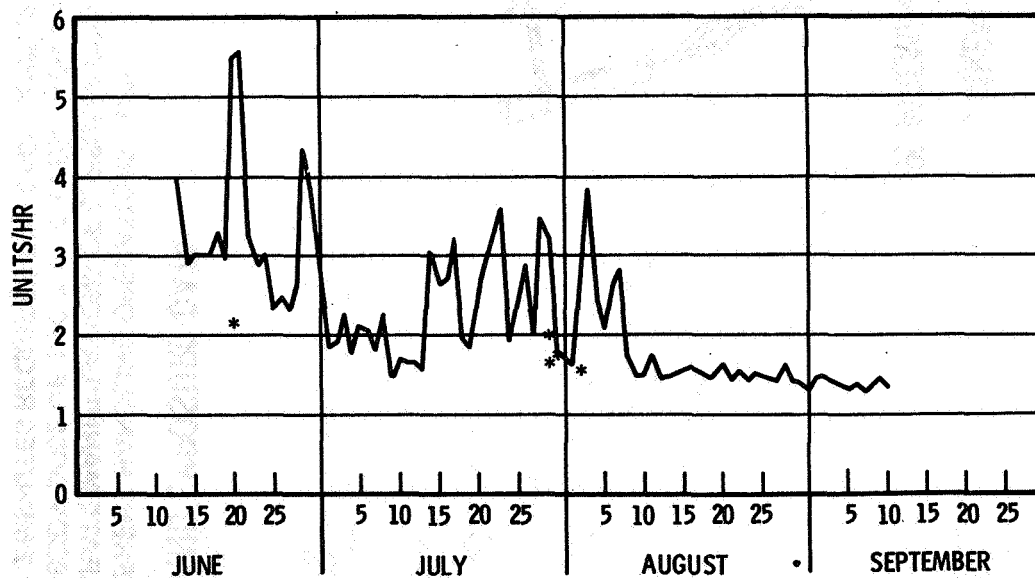


Figure 5.- Measurement of radioactivity on daily filters from the air monitor (daily reading of air-monitor ratemeter).



* VARIATIONS IN MEASUREMENT AT EARLY AND LATE TIMES AFTER REMOVAL.

Figure 6.- Measurement of radioactivity on daily filters from the air monitor (measurement from isotope analysis unit).

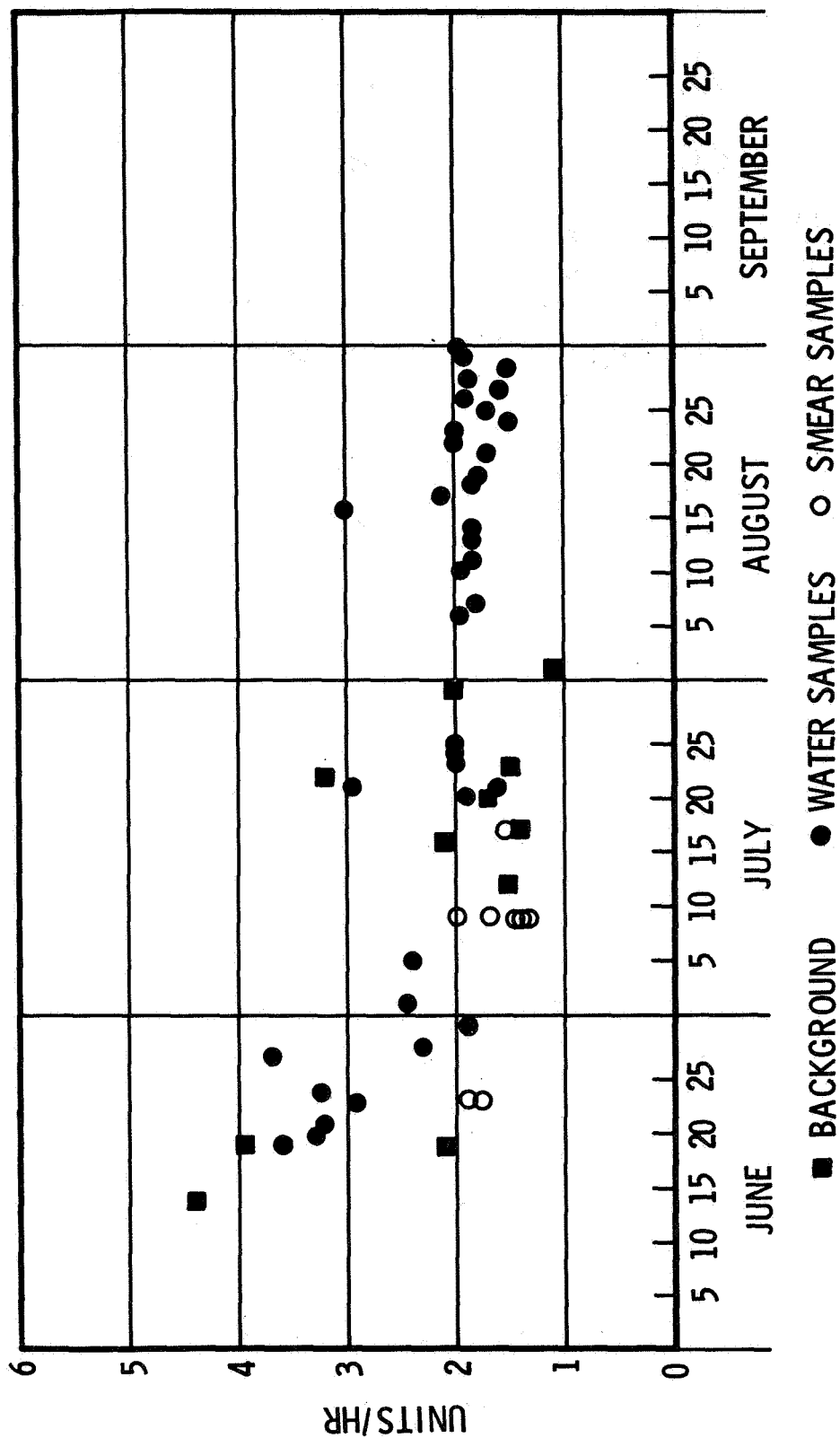


Figure 7.- Measurement of water and smear samples for radioactive contamination with the isotope analysis unit.

BODY FLUID AND BODY COMPOSITION MEASUREMENTS

By A. A. Kelton, Ph. D.

McDonnell Douglas Astronautics Company

SUMMARY

Measurements of plasma volume, blood volume, and total body water with radiopharmaceuticals, and also measurement of total body potassium by natural ^{40}K did not reveal any large changes in whole-body fluid compartments or lean body mass for the test or control subjects during the 90-day test in the Space Station Simulator. Although the changes in body fluids and lean body mass were of marginal significance, the combined results are believed to reflect differences in the physical activity among the subjects. If valid, the results suggest that a rigorous physical conditioning program is necessary to maintain body composition in such a confined space. This study further indicated that improved methods for measuring body fluids and body composition must be developed and tested in a Space Station Simulator if potentially hazardous changes in body fluid compartments are to be adequately monitored for the zero-g environment of long-duration space flight.

INTRODUCTION

Measurements of whole-body fluid compartments and lean body mass have become high priority requirements because of evidence of major problems in adaptation to zero gravity. These problems are not only of scientific interest for Skylab and Space Station studies, but may endanger the health and safety of astronauts for long-duration space flight. Since alterations in fluid volumes and lean body mass may also result from the inactivity associated with confinement, any changes that occur in a simulated environment at earth gravity must be documented to establish a baseline for interpretation of changes at zero gravity. In addition, measurements of body fluids and lean body mass are required for a more accurate interpretation of medical measurements used to monitor the health of the crew and determine any biological effects of the environment in the Space Station Simulator.

As a consequence, total body water, plasma volume, blood volume, and ^{40}K content of the whole body were measured as a part of the medical monitoring program for the crew of the Space Station Simulator during the 90-day test of a regenerative life support system.

EXPERIMENTAL PROCEDURES

Radiopharmaceutical Procedures

Using radiopharmaceuticals, total plasma and blood volumes, total body water, and lean body mass were determined for six normal, healthy, young (age 21 to 35) male volunteers. Two individuals served as normal controls and the other four were crewmen in the Space Station Simulator (SSS) for 90 days. Baseline determinations for all six individuals were obtained 6 days before the entrance of the four experimental subjects into the SSS. This allowed partial excretion of the radionuclide burden, especially tritium, before the simulator study. The three determinations were repeated on the same six individuals immediately upon egress from the 90-day test. In addition, a total body water determination with tritium was performed on the 61st day of the simulator run by having the subjects drink tritiated water stored on board.

The plasma and blood volume determinations were made by M. B. Cohen, M. D., a consultant and medical specialist in radioisotope methodology. Using standard medical procedures, plasma volume was measured by intravenous injection of 10 μ Ci of ^{125}I -RISA for each determination. After allowing a 15-minute interval for equilibrium, a blood sample was taken by venapuncture. Plasma volume (PV) was determined by

$$\text{PV} = \frac{(\text{cpm/ml of standard solution}) (\text{dilution factor}) (\text{ml injected})}{\text{cpm/ml of postinjection sample}}$$

Total blood volume (TBV) was determined from the hematocrit (Hct) as follows:

$$\text{TBV} = \frac{\text{Plasma Volume}}{1 - (\text{Hct} \times 0.91)}$$

The counting error was always reduced to less than 1 percent.

Total body water (TBW) was determined with tritiated water ($^3\text{H}_2\text{O}$). Total body waters were measured by and under the supervision of N. Telfer, M. D., in laboratories in the medical school of the University of Southern California. Approximately 1 ml was mixed in a drinking cup of water and administered to the subject orally. A second 1-ml sample was kept as a standard. Accurate determination of the dose and standard was made by weighing the syringes with the tritiated water before and after administration on a laboratory balance accurate to 0.001 mg. Urine specimens were collected from each subject at 3 and 5 hours. Water was separated from electrolytes, protein, etc., which interfere with counting, by freeze-vacuum distillation.

One ml of the distillate was added to the counting solution and the standard and samples counted in a liquid scintillation counter.

$$\text{Calculation: TBW (L)} = \frac{\mu\text{Ci administered}}{\mu\text{Ci/L in sample}}$$

Because of the reclamation of drinking water from urine during the 90-day test, the routine determination of TBW was modified. For the baseline determinations, the subjects were given about 20 percent of the usual dose (150 μCi), or 30 μCi of tritiated water. The onboard dose given on the 61st day of the test was also 30 μCi . The subjects were each given a 90 μCi dose after egress when they were able to utilize biological excretion to reduce radiation exposure. The maximum counting error for the sample was 2 percent.

Potassium-40 Measurement

The natural content of potassium-40 was measured in the same six subjects 3 days before the 90-day test and on the afternoon of egress.

Measurements were performed in the total-body counter at the University of California at Los Angeles under the supervision of N. S. MacDonald, Ph. D. The total-body counter was calibrated in terms of total potassium before the measurements. Natural potassium-40 and total potassium exist in a fixed ratio in biological materials.

RESULTS

Plasma Volume and Blood Volume

The results of plasma and blood volume measurements are shown in table 1. The precision of the measurement of plasma volume has a coefficient of variation of less than 1 to 2 percent. Significant differences (increases) in plasma volumes were observed in three of the four test subjects. Blood volume determinations were less accurate, but differences may have been measured in two of the test subjects and both control subjects. However, none of the changes can be regarded as significant since they lie within the range of normal human variation. Nevertheless, since the subjects acted as their own controls, such changes may be considered indicative.

Total Body Water

Table 2 shows the measurements of TBW of the subjects during the 90-day test. Measurements were made before the test, on day 61, and immediately upon egress. Unfortunately, the standard for day 0 was lost enroute to the laboratory so that the absolute values of these measurements are unknown. The day 0 values were calculated from the relative determinations, the specific activity of the original solution, and the dilution factor. As a result, the changes noted in TBW for each subject are not meaningful. However, a comparison of the relative changes between subjects and controls might have some indicative value since the precision of measurement should be about 1 percent. Thus, analysis of the data with the "t" test for unpaired variates shows that the average gain in TBW for the subjects was greater than the gain in TBW for the controls at the 90 percent level of confidence. Consequently, some increase in TBW for the crew may have occurred during the 90-day test.

Potassium-40

Potassium-40 was measured in the UCLA total-body counter pre- and post-test in order to determine whole-body potassium. These results are shown in table 3. Total potassium is considered to be an index of lean body mass. The normal coefficient of variation for the precision of the measurement of potassium is 2 to 4 percent. It was the opinion of Dr. MacDonald that test subjects 1 and 2 and control subject 6 showed a significant loss of whole-body potassium. There was no significant difference between the average changes in the test subjects and those in the control subjects.

Absorbed Dose from Radiopharmaceutical Determinations

The calculated radiation exposure from ^{125}I -RISA was 6-mrad whole body radiation for each of the two determinations (ref. 1) as calculated by Dr. Cohen.

Dosimetry calculations for the tritium determinations gave a total body dose of less than 10 mrad for the three determinations combined (N. Telfer, M.D., and G. Harwood, Private Communications). These calculations accounted for recycling of $^3\text{H}_2\text{O}$ during the 90-day test.

DISCUSSION

Although the changes in body fluids and lean body mass were, at best, marginal, the trend of the combined results may reflect the effects of differences in physical conditioning of the subjects. A prolonged exercise program will generally increase blood volume and plasma volume. Thus, the increase in plasma volume and blood volume in crewman 3 may be the result of his intensive and prolonged exercise program after entering the SSS.

Crewman 4 appeared to be the best physically conditioned of the crewmen before the test and his onboard exercise would not, therefore, be expected to affect his plasma volume and blood volume. Crewman 2 increased his exercise program in the mid-30 days of the 90-day test and subsequently maintained a higher ergometer workload. This may have increased his plasma and blood volumes. The control subjects had sedentary jobs during the test which may account for their apparent losses in plasma and blood volume. In general, the same tendencies were reflected by the measurements of potassium-40. Those subjects showing decreases in total-body potassium indicative of losses in lean body mass also exercised the least during the 90-day test; while those subjects pursuing a prolonged and rigorous exercise program showed a tendency to maintain or gain lean body mass. If the foregoing observations are valid, the results suggest that a rigorous physical conditioning program is necessary to maintain body composition in a confined space.

The results of the total-body water measurements were particularly disappointing. The spurious data obscured any meaningful interpretation. Nevertheless, some credibility should be given to the relative intercomparison of data and the measurements which followed egress from the Space Station Simulator. These results indicate that the test subjects had a greater amount of total body water that would be predicted from body weight. Further, the crew showed a greater increase in total body water than the control subjects. However, such results are not in general agreement with the measurements of plasma and blood volumes and total body potassium or the differences in physical conditioning of the crew. It would seem that any increase in total body water should be accounted for by some environmental factor that was common to the entire crew other than exercise.

One obvious result of this study was that current methods of measuring body composition and fluid compartments would be inconvenient, traumatic, and subject to uncertainty if the measurements had to be regularly performed in the actual environment of a Skylab or Space Station by inexperienced personnel with onboard equipment and materials. Since the health and safety of astronauts may be endangered by changes in body fluid compartments in a zero-gravity environment, methods of measurement must be developed for use in spacecraft which are accurate, reliable and noninvasive. Recent innovations which measure trace amounts of deuterium oxide in saliva samples by infrared spectrophotometry or gas chromatography should be evaluated. Electrical measurements such as whole-body impedance and high sensitivity nuclear magnetic resonance are promising techniques for determination of total body water, extracellular fluid, and intracellular fluid. Prototype measuring systems should be evolved and medically evaluated during future, longer duration, manned, one-g simulations.

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TABLE 1.- PLASMA AND BLOOD VOLUMES OF SUBJECTS IN THE
90-DAY TEST OF A SPACE STATION SIMULATOR

SUBJECT	PLASMA VOLUME (ML)			BLOOD VOLUME (ML)		
	DAY 0	DAY 90	Δ BASELINE	PREDICTED	DAY 0	DAY 90
1	2,905	2,801	-104	4,700	4,663	4,669
2	2,779	2,920	+141	4,350	4,495	4,787
3	3,019	3,222	+203	5,070	5,317	5,370
4	3,586	3,575	-11	5,290	*6,162	5,959
5	2,896	2,834	-62	4,900	4,827	4,645
6	2,580	2,520	-60	4,460	4,433	4,201

*BLOOD VOLUME IS 76.1 ML/KG BODY WEIGHT WHICH IS WELL WITHIN THE NORMAL RANGE OF 68 TO 88 ML/KG.

TABLE 2.- TOTAL BODY WATER OF SUBJECTS DURING THE
90-DAY TEST OF A SPACE STATION SIMULATOR

SUBJECT	DAY	TBW PREDICTED*	TBW CHANGE*	MEAN Δ TBW*	TBW MEASURED	TBW CHANGE	MEAN Δ TBW			
1	0	35.1	+0.1L	+3.0L	35.8	+6.1L	+6.0L			
	61	35.3			44.0					
	90	35.1			39.8					
2	0	36.6	+0.3L		35.9	+4.9L		+3.0L		
	61	37.9			40.4					
	90	37.9			41.1					
3	0	43.1	-0.6L		42.4	+5.5L			+3.0L	
	61	42.4			47.3					
	90	42.6			48.4					
4	0	45.6	-1.0L		46.2	+7.5L				+3.0L
	61	44.8			53.3					
	90	44.5			54.0					
5	0	41.1	+0.7L	-0.2L	44.2	+2.2L	+3.0L			
	61	41.8			46.7					
	90	41.8			46.0					
6	0	38.5	-1.1L		35.5	+3.7L		NET INCREASE 3.0L		
	61	37.4			38.6					
	90	37.4			39.8					

*PREDICTED FROM BODY WEIGHT AND AGE BY N. TEFLER, M.D.

TABLE 3.- MEASUREMENT OF WHOLE-BODY POTASSIUM IN SUBJECTS BY
COUNTING K-40 WITH THE UCLA TOTAL-BODY COUNTER

SUBJECT	BEFORE		AFTER		90-DAY Δ gK	COMMENT
	gK	gK/kg	gK	gK/kg		
1	158.9	2.75	148.9	2.52	-10.0	SIGNIFICANT LOSS
2	156.5	2.65	147.2	2.37	-9.3	SIGNIFICANT LOSS
3	178.2	2.42	182.4	2.44	+4.2	
4	190.4	2.37	191.9	2.39	+1.5	
5	164.9	2.37	161.6	2.21	-3.3	
6	172.2	2.71	162.0	2.67	-10.2	SIGNIFICANT LOSS

NO SIGNIFICANT DIFFERENCE BETWEEN SUBJECTS AND CONTROLS

SOME BIOCHEMICAL DETERMINATIONS ON SERUM FROM CREWMEN
PARTICIPATING IN A 90-DAY SPACE STATION SIMULATOR TEST

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and David E. Uddin (Clinical Medical Sciences Department)

Naval Medical Research Institute
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SUMMARY

Numerous alterations in the biochemical assays of serum were observed in the crewmen of the Space Station Simulator during and after the 90-day test. These alterations are evaluated in relation to the mean pre-test values with each man serving as his own control. Although the test was judged to be totally benign by the medical staff, the biochemical alterations are tentatively attributed to either the exercise program or the psychological or other stress factors. Final interpretation must await evaluation of these data with the data obtained by other research groups involved in this study.

INTRODUCTION

A basic premise for the success of an operational orbiting laboratory is that man will be able to survive long periods of time under potentially stressful conditions. These comprise both physiological and psychological components, and can be divided most conveniently into the following: 1. Zero gravity, 2. prolonged exposure at pressures less than 1 atm, 3. trace component toxic effects, and 4. minimum contact with the "outside world" and resulting forced small group interaction. The recent study carried out for NASA at McDonnell Douglas Astronautics was basically an engineering exercise at 1 g designed to test the regenerative life support system and the feasibility of prolonged human habitation under these conditions. This test also allowed two types of biomedical analysis to be carried out. A small aliquot of blood was drawn on board and subjected to routine clinical analysis under the direction of Dr. J. Wamsley (MDAC). The reported values were to serve as immediate clinical indicators to spot changes that might impair or abort the mission, or to determine if there were serious physiological changes that could prove injurious to the health of the subjects. A second set of samples was drawn for analysis of serum lipids, enzymes, and other minor biochemical constituents. These analyses were intended to provide information on the extent and nature of subtle biochemical changes which might be useful as indicators of stress. Changes in minor phospholipids have been reported to occur after acceleration stress, combat stress, and in schizophrenia (Polis *et al.*)(1). Data from these laboratories have indicated that severe psychological stress may be reflected in serum lipids and it is well known that

there are hormonal and neurological factors controlling serum free fatty acid levels. Physical stresses and specific tissue damage are most conveniently assessed by examination of serum enzymes and isozymes. The nature and magnitude of the changes observed in this test are correlatable with some existing literature; however, much of the information gathered is unique and will require interpretation from a combination of physiological, psychological, and biochemical observations.

METHODOLOGY

Fasting blood samples were obtained between 0600 and 0700 by venipuncture using partially evacuated 15 ml containers. The blood was allowed to clot for 30 ± 10 min. The tubes were then centrifuged. Serum was withdrawn and placed in CHCl_3 -MeOH washed (lipid-free) screw-capped vials, packed in ice, and shipped via air freight to our laboratories. The analysis was begun within 24 hours of sampling. Commercial lyophilized serum was used as a control for serum enzyme analysis. Pooled frozen serum, genetic type 2-1, was used for haptoglobin analysis. Chemical standards were controls for glucose, lactate, cholesterol, and free fatty acids. No satisfactory controls existed for the other determinations. Neutral and phospholipid distributions were determined by standard procedures developed in this laboratory (2,3). Lipoproteins were determined by a modification of Noble's procedure with quantitation being accomplished by densitometry (4).

Enzyme determinations: Total lactic dehydrogenase (LDH) was determined by the method of Babson and Phillips (5). LDH isozymes were detected after electrophoresis in 0.9% agarose on microscope slides and quantitated by densitometry. The electrophoresis was carried out in 0.05 M barbital, pH 8.6, for 25 min at 150 volts. Alkaline and acid phosphatase were determined using Boehringer Mannheim kits. Creatine phosphokinase (CPK) was determined by a Calbiochem kit. Amylase was determined by a modified Cherry-Crandall starch hydrolysis method supplied as a kit from Harleco.

Other serum measurements: Glucose was measured as true glucose by the glucose oxidase method (Worthington Glucostat^R). Lactate was determined by a modification of the method outlined in Bergmeyer (6). Cholesterol was analyzed by the Liebermann-Burchard reagent (Harleco). Non-esterified fatty acids were quantitated by a modification of Novak's method (7).

RESULTS

Table I indicates the analyses that were performed on the serum samples. Inspection of the test results showed that few components of serum were significantly altered by the 90-day exposure. Among the non-lipid constituents, glucose was quite stable with the only remarkable variation being a general small decrease in all subjects on mission day 53. The mean serum lactate values were found to range from 23-27 mg%. The serum enzymes showed some

regular fluctuations, but few clearcut changes relative to the test could be ascertained. Lactic dehydrogenase, acid and alkaline phosphatase showed no significant change throughout the test period. Creatine phosphokinase (Figure 1) was significantly elevated in crewman #2 on days 11, 39, and 60. Crewman #4 had high CPK levels prior to the 90-day run, and these were further increased during the run. These changes will be discussed in relation to exercise phenomena and adaptive changes. Serum amylase levels (Figure 2) were increased over the pre-test mean in all subjects with crewmen #3 and #4 showing the most significant elevations. Of the serum lipid classes analyzed, the only noteworthy phospholipid change was in sphingomyelin (Figure 3). A significant elevation of sphingomyelin was observed for crewmen #1 and #2 on day 18. Crewman #4 had an elevated value throughout the run while most of the values for crewman #3 ran below the pre-test mean. In the neutral lipids, cholesterol (Figure 4) showed a steady decrease during the run. The low values persisted throughout the post-test period.

DISCUSSION

In general the biochemical values that were determined over the course of this study indicate no marked alteration that could be interpreted as hazardous to these men.

One subject, crewman #2, had three elevations in creatine phosphokinase after entry into the chamber, each elevation being lower than the previous rise. Such an increase in CPK may accompany skeletal muscle injury or severe exercise. A prolonged exercise routine can lead to progressively less significant enzyme changes resulting from an unchanged exercise regimen; this phenomenon, a type of adaptation, could possibly account for the pattern observed in this subject.

Serum amylase was elevated in all subjects during the run. The origin of this enzyme (parotid or pancreatic) was not determined and no explanation for the rise can be offered at this time.

In all of the subjects there was no detectable change in the minor phospholipids measured as the sum of phosphatidyl glycerol, cardiolipin and phosphatidic acid. If Polis (1) is correct that elevation of phosphatidyl glycerol is an indicator of "stress", no evidence of stress such as found in acceleration, combat aviation, and schizophrenia was apparent in the chamber crew. The analytical techniques used by Polis, however, were different than those applied here, and direct comparisons are not possible.

In all of the subjects the values for cholesterol fell during the test and remained low after the test. This could be due in part to diet and exercise but, without dietary analysis, this concept is only speculative. There have been reports of both a rise and a decline in cholesterol levels associated with exercise.

The sphingomyelin pattern is interesting in all of the crew members. This phospholipid is increased in combat aviators (1). In an earlier study by this laboratory of isolation stress (unpublished data--Project RIM) one subject became very upset emotionally. At this time, his serum sphingomyelin was at these same high levels and remained high for the next day even though the isolation had been terminated. In our hyperbaric experiments on humans no rise in sphingomyelin has been observed. It will be interesting to see if these data show any correlation with the physiological and psychological observations.

The serum lipoproteins were considered to have shown no significant change. These analyses were performed because serum lipids are transported bound to proteins and, if there was a pronounced change in serum lipids, alterations in the lipoprotein pattern might be expected.

Glucose and lactate showed no changes of any significance in this hyperbaric environment.

When it was noted that one subject had an apparent ahaptoglobinemia prior to the test, the authorities on the test site were immediately notified. Examination of the subject, however, did not reveal any abnormalities. Since haptoglobins are the normal mechanism for binding of free hemoglobin, a sudden decrease could indicate a hemolytic episode.

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TABLE I

Serum Biochemical Analyses Performed During
the 90-Day Space Simulator Test

Neutral Lipids: Monoglyceride, free fatty acids, cholesterol, diglyceride, triglyceride, cholesterol esters.

Phospholipids: Lysophosphatidyl choline, sphingomyelin, phosphatidyl choline (inc. phosphatidyl serine and inositol) and minor phospholipids.

Lipoprotein Distribution: α , pre β , β

Serum Enzymes: Acid phosphatase, alkaline phosphatase, amylase, creatine phosphokinase, lactic dehydrogenase

Other Constituents: Cholesterol (chemical), free fatty acids (chemical), glucose, lactate, haptoglobin.

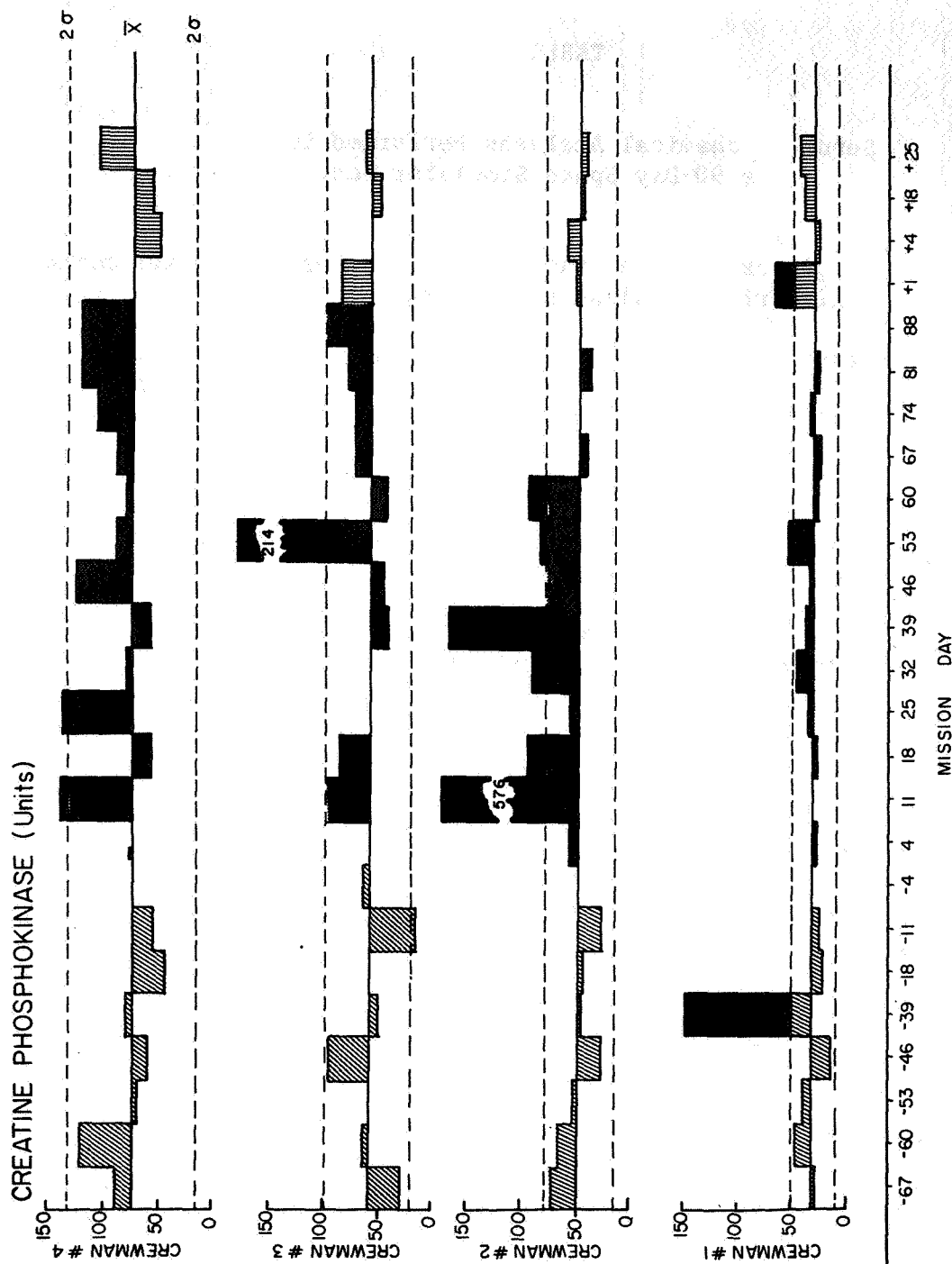


Figure 1.- Serum levels of creatine phosphokinase activity. Minus and plus signs on mission days denote pre-test and post-test days, respectively. Solid black shading indicates values that exceed 2 times the standard deviation from the pre-test mean.

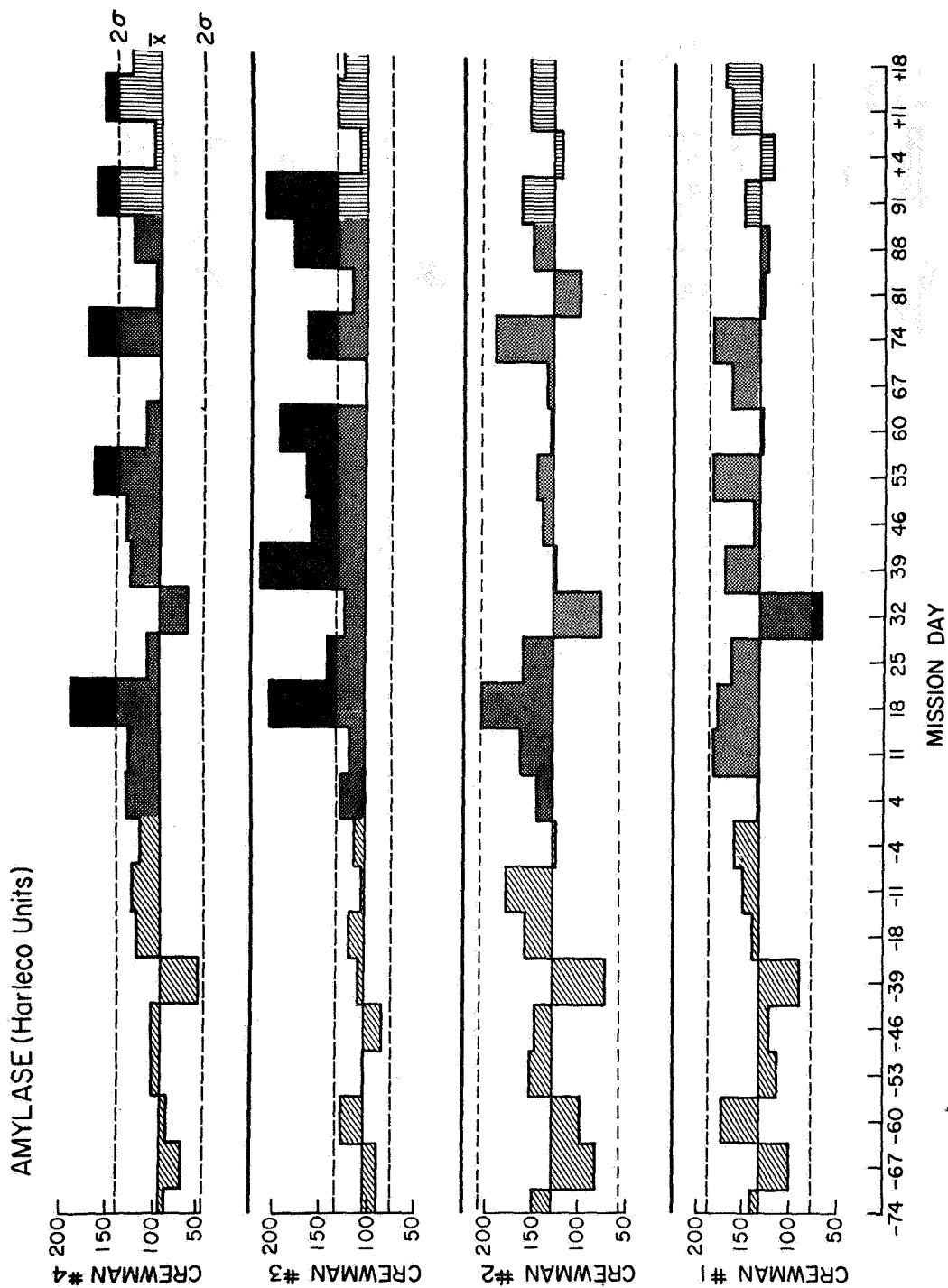
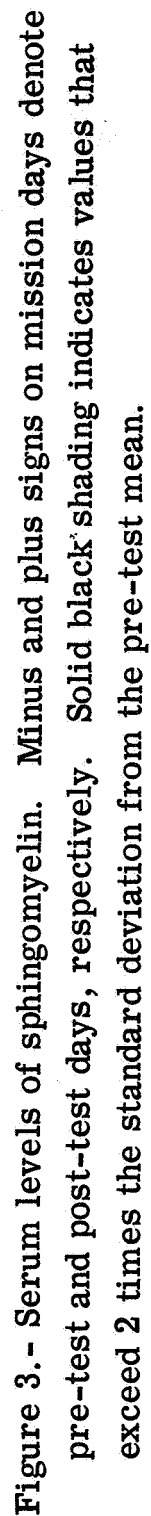


Figure 2.- Serum levels of amylase activity. Minus and plus signs on mission days denote pre-test and post-test days, respectively. Solid black shading indicates values that exceed 2 times the standard deviation from the pre-test mean.



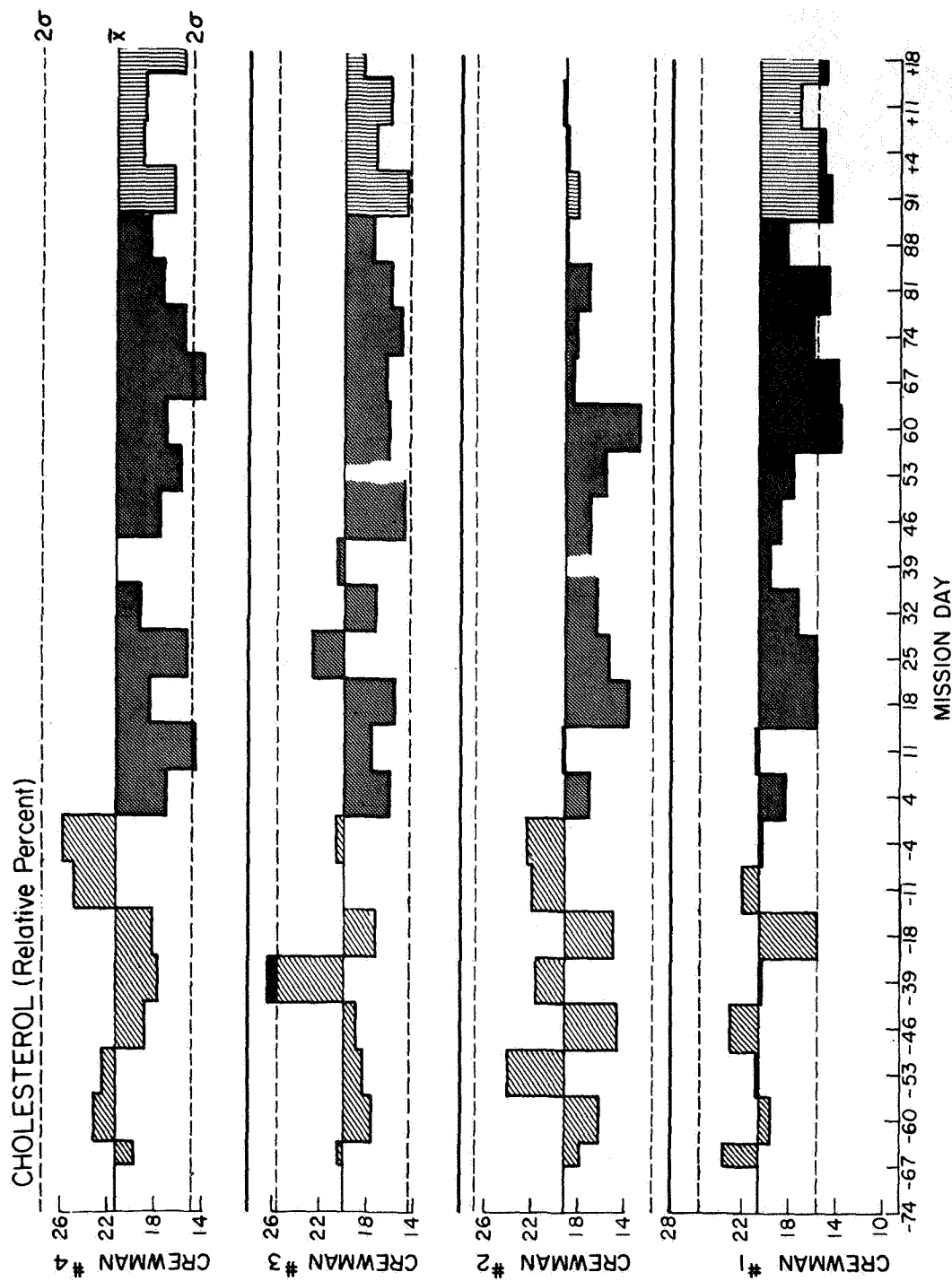


Figure 4.- Serum levels of cholesterol. Minus and plus signs on mission days denote pre-test and post-test days, respectively. Solid black shading indicates values that exceed 2 times the standard deviation from the pre-test mean.

UTILIZATION OF THE $V-\dot{V}$ SPIROMETER LOOP TECHNIQUE

FOR RESPIRATORY MONITORING

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SUMMARY

The $V-\dot{V}$ spirometer loop technique was successfully used in the 90-day manned test for respiratory monitoring. Only temporary small changes occurred in the respiratory systems of the test subjects during the test period. Because the technique is easy to use, requires very little time, and detects minor changes, it is recommended as a means of monitoring the subjects in subsequent reduced-pressure-atmosphere closed-chamber tests and space flights.

INTRODUCTION

Pulmonary function measurements are useful in evaluating the condition of an individual's respiratory system and for detecting changes from disease, modified atmospheric conditions, and environmental contaminants. The volume--volumetric-flow-rate loop technique is a quick convenient method for obtaining simultaneously several parameters of respiratory physiological data in a compact form. In this form the data are easy to compare on a time basis and convenient to store. Although the technique is not in general clinical use, considerable research has gone into its development. (See refs. 1 to 9.)

SYMBOLS

V	volume
\dot{V}	volumetric flow rate

DISCUSSION

Figure 1 shows a typical $V-\dot{V}$ loop from a respiratory test. The curves indicate respiratory volume as a function of volumetric flow rate for both inspiration and expiration. The inner loop represents normal tidal volume and volumetric flow rate, and the outer curve represents the maximum volume and flow rate which the subject can achieve. The maximum volume which the subject can move in and out of his lungs is his vital capacity. The volumetric difference between the inner normal tidal loop and the outer loop on expiration is his expiratory reserve, and the difference on inspiration is his inspiratory reserve.

Maximum volumetric flow rates are a measure of the elasticity and resiliency of a subject's lungs.

Figure 2 presents a diagram of the apparatus used in the 90-day manned test. During a respiratory test, the subject breathes into the spirometer through either a mouthpiece or a face mask. The spirometer is a 14-liter, positive-displacement-type device with a lightweight bellows. A pressure loading of less than 1 mm of water is required to move the spirometer bellows; this thus causes a minimal pressure loading on the test subject. The spirometer produces simultaneous electrical outputs for volume and flow rate. The dc signals from the transducer are amplified and fed into a storage oscilloscope. During a respiratory test, the necessary information to complete the loop is stored on the screen of the oscilloscope. If the data loop is properly completed, the trace is photographed on a $3\frac{1}{4}$ -inch by $4\frac{1}{4}$ -inch film with an oscilloscope camera.

Figure 3 shows the spirometer installed in the test chamber during the 90-day manned test. During this test the V-V loop technique was applied to detect possible changes in the subjects from contaminants, confinement, infection, and the reduced-pressure mixed-gas atmosphere.

Figure 4 shows oscilloscope traces of a person with no detectable pulmonary system dysfunction and of a person with marked dysfunction. This figure is used for illustration and is not of the subjects in the 90-day manned test.

Figures 5 and 6 show oscilloscope traces of test subjects 1 and 3 in the 90-day manned test. Subject 1 had a smaller than normal vital capacity, whereas subject 3 had a greater than normal vital capacity. These loops show highly individualistic characteristics. Respiratory tests were performed on the subjects before the 90-day manned test, once each week during the test, and at one and four days after the test.

No major changes or infection were noted in the respiratory system of any of the test subjects. In the reduced-pressure atmosphere, the vital capacity of each of the test subjects decreased 5 to 10 percent while the maximum inspiratory and expiratory volumetric flow rates increased from 5 to 20 percent. Immediately after the 90-day manned test, both tidal volume and volumetric flow rate returned to a value between the pretest and test levels. Possibly changes in the involuntary breathing pattern in the reduced-pressure atmosphere caused these minor changes; however, further research is needed to confirm this effect.

Small oscillations in the outer curve indicated very mild congestion for subject 3 before, during, and after the 90-day manned test. This may be a worthy subject for further investigation.

CONCLUDING REMARKS

The volume—volumetric-flow-rate loop technique appears to have been a useful method of pulmonary monitoring during the 90-day manned test. Respiratory changes observed during the test were relatively minor. The spirometry

equipment operated satisfactorily during the test and required no repairs. For future reduced-pressure-atmosphere closed-chamber tests and space flights, more compact spirometry equipment is desirable and should be developed.

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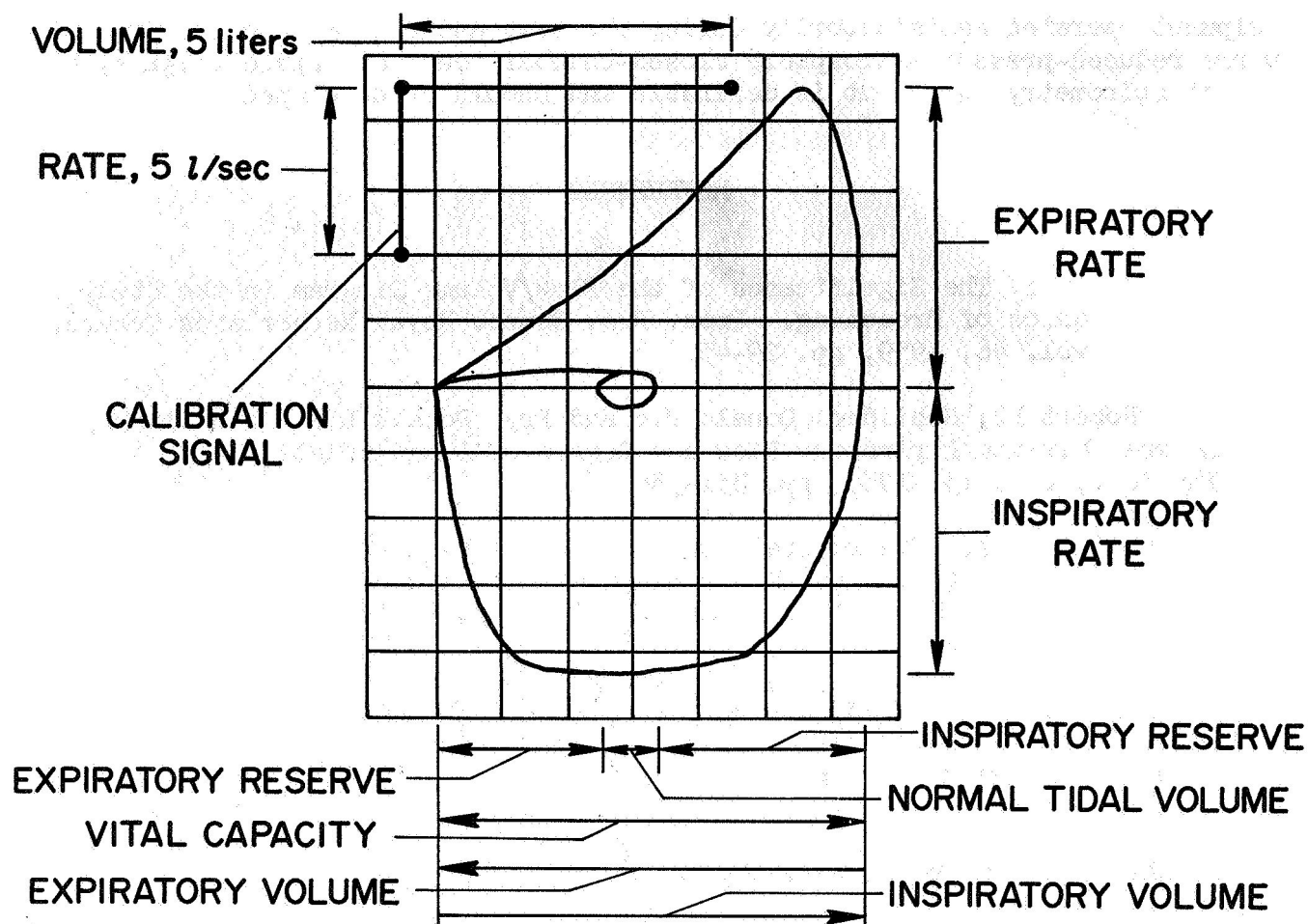


Figure 1.- V- \dot{V} loop method.

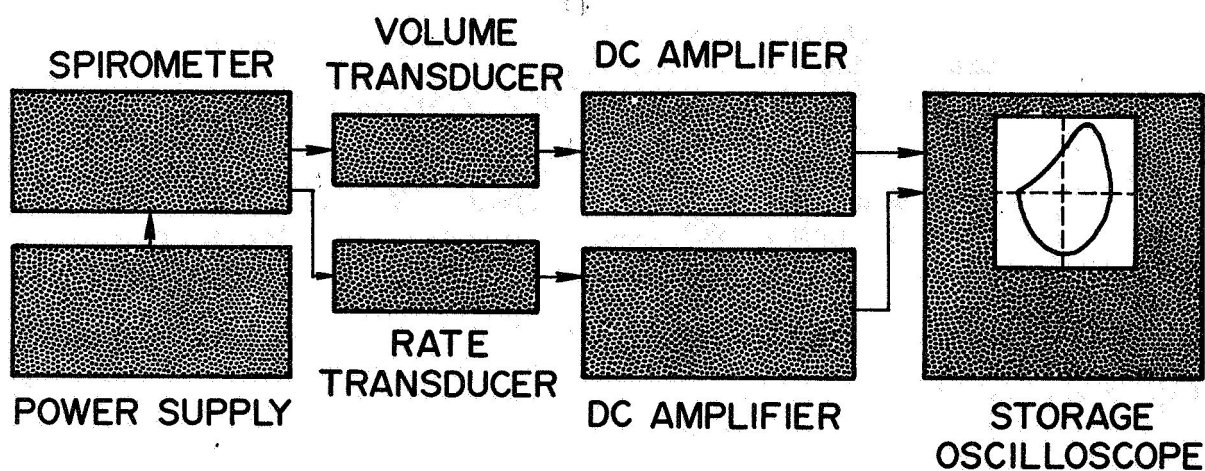
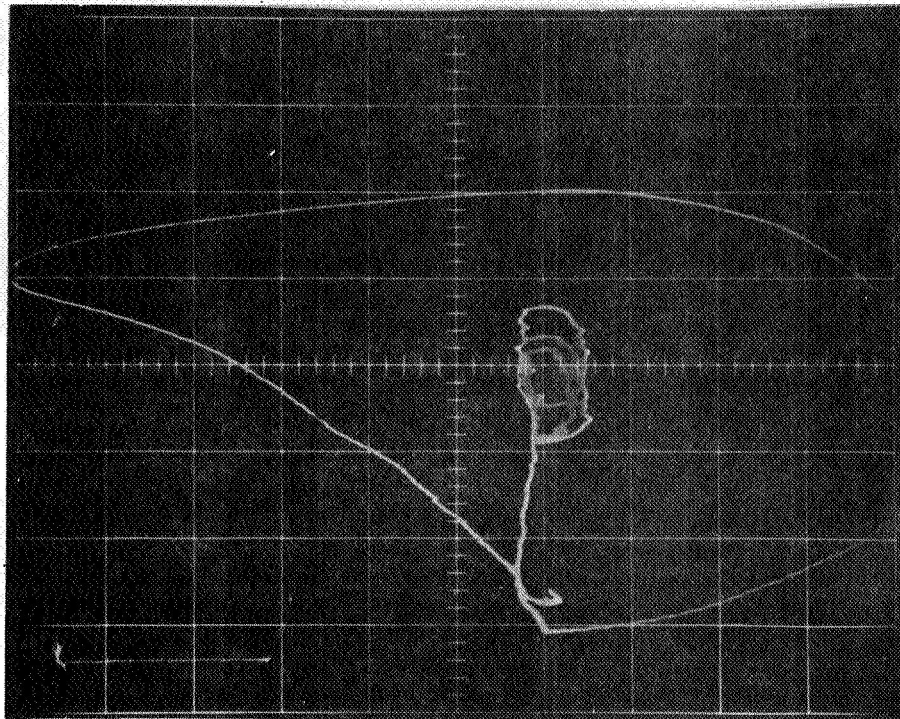


Figure 2.- Diagram of apparatus for obtaining pulmonary loops.



Figure 3.- Subject using spirometer during 90-day manned test.

MALE, AGE 36
NONSMOKER



MALE, AGE 50
HEAVY SMOKER

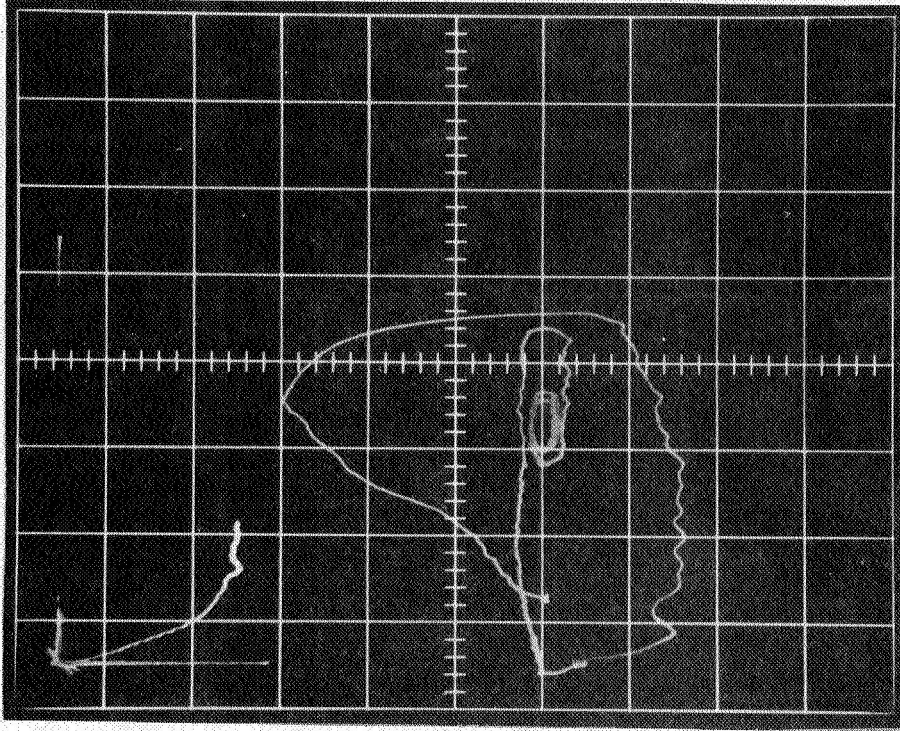
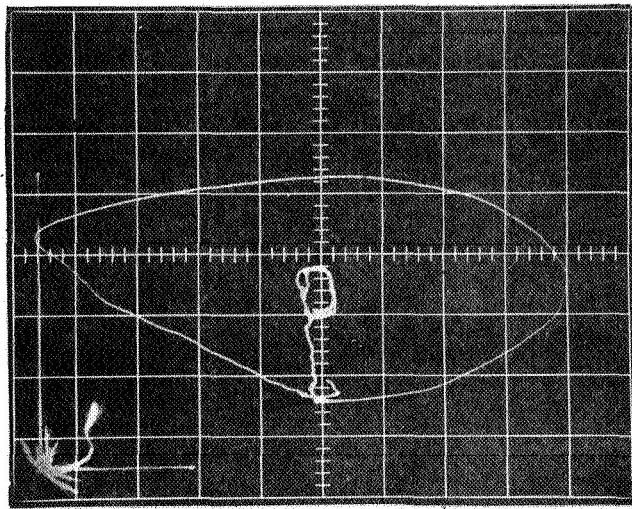


Figure 4.- Pulmonary loops for persons with healthy and weak lungs.

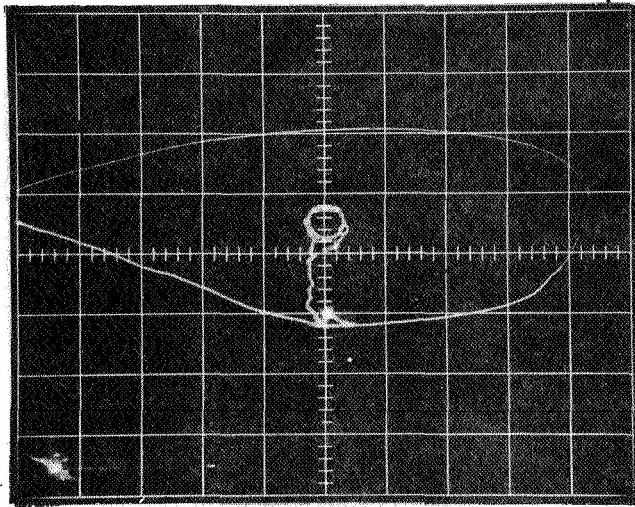
6/4/70

BEFORE TEST



9/2/70

DURING TEST



9/12/70

AFTER TEST

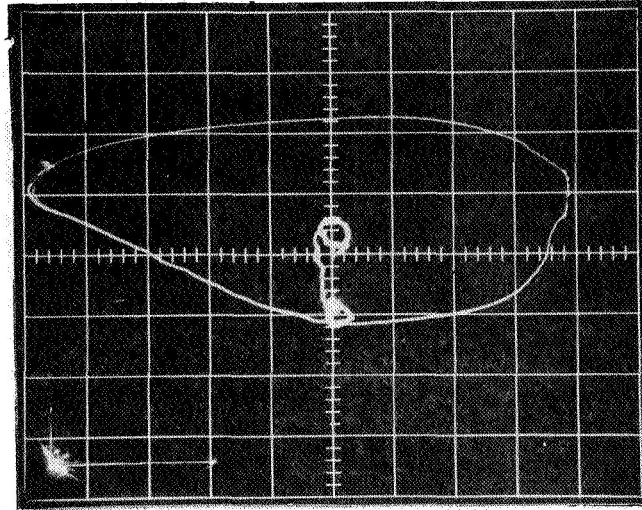
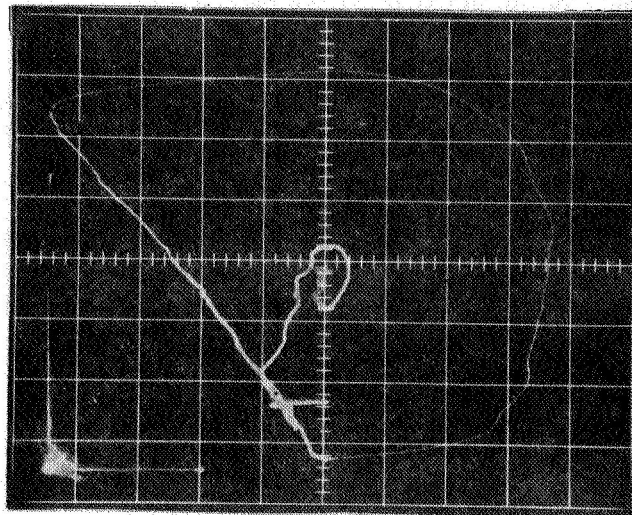
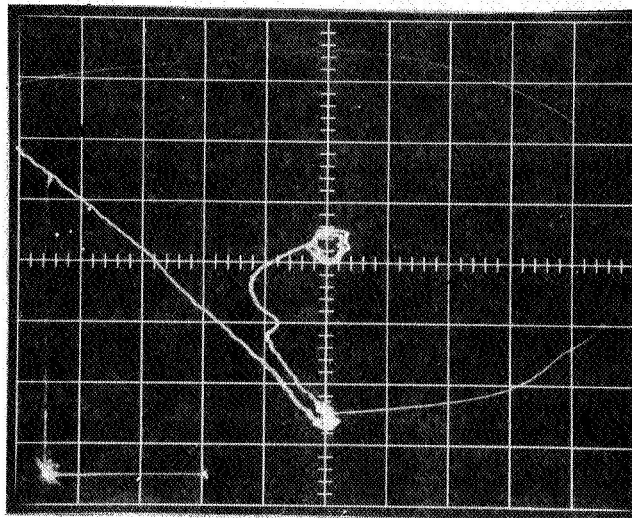


Figure 5.- Pulmonary loops for subject 1.

6/4/70
BEFORE TEST



8/12/70
DURING TEST



9/15/70
AFTER TEST

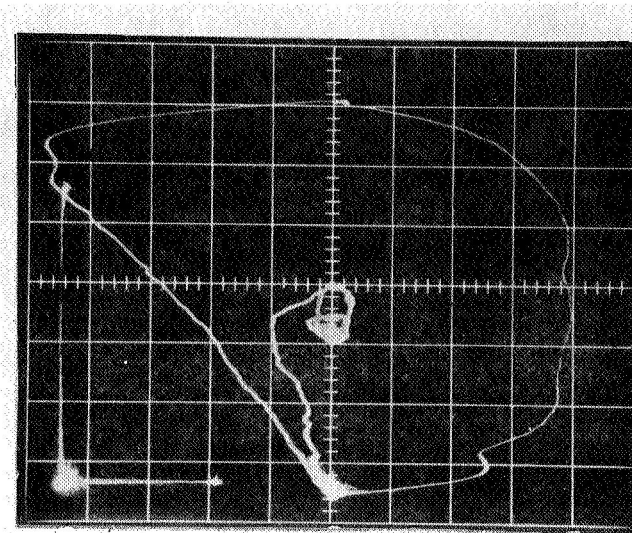


Figure 6.- Pulmonary loops for subject 3.

VE (L/min) - 40 (3)

2X.5

BLOOD CARBOXYHEMOGLOBIN SATURATION OF PERSONNEL

DURING NINETY-DAY TEST^{1,2}

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SUMMARY

Hemoglobin solutions prepared from blood clots have been used to measure the COHb saturation of crew members during a ninety-day test of a Simulated Space Station (SSS) life support system. The Hopcalite toxin burner was effective in removal of CO from the system as rapidly as it was produced by the crew. During a period of 313 hours when the toxin burner was not operated, a total of 739 ml of CO accumulated in the gas and blood. An average rate of endogenous CO production over this period of 0.59 ml per man hour was calculated.

INTRODUCTION

Control of the gaseous environment quality to suitably serve as the respiratory gas is critical when men are confined in a restricted space for long periods of time. Adequate removal of toxic materials is essential whether these compounds are produced by metabolic reactions of the crew or by chemical reactions related to operation of the equipment used. Adequate removal of carbon dioxide, produced in large quantity by the crew, and provision for maintenance of appropriate oxygen levels are prerequisite to any such closed system.

One such metabolic toxic material, carbon monoxide, is considered in this report. Although CO is released in relatively small amounts by off-gassing of many chamber materials (1,2), the contribution of the total CO production from this source in a satisfactory manned system is insignificant. Major sources of CO production, as from fire and overheating of organic materials, are to be scrupulously avoided. The endogenous metabolic production of CO by the crew members (3,4) is unavoidable and provision must be

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²The opinions or assertions contained herein are those of the authors and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

made to prevent its accumulation. Ideal CO control of the gas composition will result in a constant low level of carboxyhemoglobin saturation of the crew predictable from the known gaseous levels of O₂ and CO. When CO is not removed from the gas phase, its concentration will increase from continued production by the men. The rate of CO accumulation, in both the gas phase and in the blood of the crew under these conditions, may be used to estimate the rate of endogenous CO production.

MATERIALS AND METHODS

Blood clots remaining after serum removal for other biochemical analyses were the materials used for COHb saturation measurement. The clots were air shipped in ice, received in the laboratory in the original stoppered and labelled tubes, and were refrigerated at 4°C without opening until the day of analysis.

Hemoglobin solutions were prepared from the clots for analysis as follows. The tube containing the clot was opened and the clot transferred to a 20 ml plastic disposable syringe. The clot was expressed through the syringe orifice (no needle) back into the original tube. A volume of 2% Sterox SE in water was then added to the tube such that the volume of Sterox added was approximately equal to the original volume of the clot. The tubes were stoppered and placed on a mechanical rotor at room temperature for 15 to 30 minutes to permit the Sterox to permeate the finely divided clot and hemolyze the red cells. The tubes containing the extracted clots were centrifuged to obtain a clear supernatant solution. A fraction of this hemoglobin solution was transferred to a small vial or test tube for analysis of carbon monoxide content and total hemoglobin.

Total hemoglobin was determined as cyanmethemoglobin at 540 nm by use of a mM absorptivity of 11.0 (5,6). The reaction was allowed to proceed for at least 2 hours before absorbance measurements were made because of the slow conversion of COHb to cyanmethemoglobin (7). Usually a dilution of 1:301 was used: 15 ml of reagent plus 0.050 ml of hemoglobin solution.

Carbon monoxide content was measured by gas chromatography (8). Conditions were used which prevented appreciable CO formation during the reaction in the presence of oxygen (9). All results are expressed in terms of COHb % saturation calculated as 100 times the CO content of the sample divided by the total hemoglobin content of the sample expressed in terms of CO binding capacity.

RESULTS

Samples were obtained from crew members and back-up personnel over a period of about 6 months before, during, and after the actual manned chamber test. These results in Table I show the values obtained, together with the

mean and standard deviation for each man while he was breathing the uncontrolled atmosphere of southern California. It is apparent that four men were in the range given by McCredie and Jose (10) for normal nonsmokers (0.80 ± 0.29) while the other three were more nearly like their series of smokers (4.13 ± 1.99). Indeed one man had a mean COHb level of nearly 7% with one individual sample of over 9% saturation.

Table I

Blood COHb saturation of crew personnel for the
ninety-day test while outside the SSS

Date 1970	Donlon COHb %	Dennis COHb %	Wong COHb %	Hall COHb %	Hootman COHb %	Shoemaker COHb %	Dunn COHb %
3/24	1.29	2.74	1.19	1.35	2.53	1.45	5.14
4/7	0.97	5.02	0.84	0.95	2.75	0.98	6.25
4/14	1.04	4.98	0.88	1.05	----	1.19	7.71
4/21	1.70	4.06	1.27	1.42	3.50	1.02	8.75
4/28	0.92	3.92	1.21	1.18	2.77	1.22	6.98
5/5	1.34	3.18	1.33	1.04	2.87	1.07	6.05
5/26	1.02	2.88	0.88	1.08	2.68	0.93	----
6/2	1.09	2.07	1.31	1.49	4.65	1.14	----
6/9	0.52	0.95	0.48	0.85	2.31	0.87	----
6/13	Ninety-day test begins						
6/16					0.41	----	----
6/23					----	0.60	----
6/30					2.06	----	----
7/7					2.18	----	----
7/14					----	0.99	----
7/21					----	0.61	----
7/28					2.50	----	----
8/4					----	----	9.05
8/11					3.14	----	----
8/18					2.97	----	----
8/25					3.09	1.16	----
9/1					1.96	1.13	----
9/8					1.67	----	4.94
9/11	Ninety-day test ends				4.07	0.91	----
9/15	1.27	1.39	1.15	1.28	2.66	----	7.56
9/29	1.51	4.37	1.31	1.25	3.15	2.11	6.68
10/6	0.97	2.41	0.90	0.95	2.43	0.80	6.67
Number	12	12	12	12	21	17	11
Mean	1.14	3.16	1.06	1.16	2.68	1.07	6.89
S.D.	± 0.31	± 1.34	± 0.26	± 0.20	± 0.86	± 0.34	± 1.32

Results obtained on crew members during the actual manned test are given in Table II. All these men were breathing the chamber gas and would be expected to reach nearly identical steady-state COHb levels (11). Minor variation may be expected from differences in respiratory physiology among the men (12). The mean COHb level observed for the four men on each day has been included together with the standard deviation. There is significantly less variation between the crew members during the test than was seen for a given subject on different days outside the chamber. Furthermore, all the subjects are in the range of normal nonsmokers.

Table II

Blood COHb saturation of crew members during
ninety-day test inside the SSS

Date 1970	Mission Day	Donlon COHb %	Dennis COHb %	Wong COHb %	Hall COHb %	Mean COHb %	Std. Dev.
6/13	1	Men enter chamber					
6/16	4	1.11	1.01	0.95	0.95	1.00	0.07
6/23	11	1.58	1.56	1.58	1.48	1.55	0.05
6/30	18	1.76	1.75	1.80	1.62	1.73	0.08
7/7	25	1.77	1.69	1.53	1.59	1.64	0.10
7/14	32	1.81	1.81	1.76	1.81	1.80	0.02
7/21	39	1.87	1.87	1.86	1.85	1.86	0.01
7/28	46	1.72	1.64	1.65	1.66	1.67	0.03
8/4	53	1.66	1.67	1.70	1.50	1.63	0.09
8/11	60	1.54	1.37	1.40	1.44	1.44	0.07
8/18	67	1.32	1.29	1.20	1.35	1.29	0.06
8/19	68	Toxin burner turned off					
8/25	74	1.85	1.94	1.88	1.93	1.90	0.04
9/1	81	2.25	2.42	2.34	2.32	2.33	0.07
9/1	81	Toxin burner turned on after 9/1 samples					
9/8	88	1.90	2.01	1.90	1.93	1.93	0.05
9/11	91	1.92	1.75	1.71	1.81	1.80	0.09
9/11	91	Men leave chamber					

The mean COHb level increased slowly from the test start until the sample on the 39th day, 7/21. After this a slow decrease was observed until 8/18, the 67th day. These changes reflect a change in the removal of CO from the gas by the toxin burner. This device converts CO to CO₂ by catalytic oxidation on Hopcalite at about 370°C. Variation in the efficiency of CO removal as a result of alteration in gas flow to the burner or other factors probably explains the small changes observed for the samples from the start to 8/18.

The toxin burner was shut down on 8/19 and remained off for a total of 313 hours until after blood was drawn on 9/1. A significant increase of COHb from about 1.3% to over 2.3% was noted during this period.

An approximate rate of endogenous CO production can be obtained from the increase in the amount of CO in the gas phase and in the blood of the crew over this period. For this estimate, the actual volume of the SSS, 3,790 ft³, was calculated to be 63.0×10^3 liters (STPD). The increase in CO contained in the gas was $(63.0 \times 10^6 \text{ ml}) \times (20.5 - 9.4) \times 10^{-6} = 699.3 \text{ ml}$. The increase in blood CO during this period was calculated by estimating the total hemoglobin to be 10.1 gm/Kg body weight (13). The calculated values were Donlon = 7.66, Dennis = 9.59, Wong = 11.83, and Hall = 10.93, a total increase of CO in the blood of 40.0 ml. This gives a total endogenous production of 739.3 ml of CO in 1,256 man hours or 0.59 ml of CO per man hour. This result is in quite acceptable agreement with the average value of normal endogenous CO production, 0.42 ml/man hour, reported by Coburn, et al. (4).

The Haldane law for equilibrium distribution of oxygen and CO in blood in man may be applied in vivo in the following form:

$$K = 218 = \frac{(\text{COHb})}{0.97(100 - \text{COHb})} \times \frac{(\text{P}_{\text{Bar}} - 47)f_{\text{I}O_2 - 40}}{(\text{P}_{\text{Bar}} - 47)f_{\text{I}CO}}$$

in which COHb is the % saturation of hemoglobin with CO, $(\text{P}_{\text{Bar}} - 47)f_{\text{I}O_2 - 40}$ is the equilibrium oxygen tension, and $(\text{P}_{\text{Bar}} - 47)f_{\text{I}CO}$ is the equilibrium carbon monoxide tension. This equation is valid when the inspired oxygen tension is approximately 150 mm Hg. In the steady state where CO is excreted at the same rate as it is produced, the actual inspired CO tension must be less than the equilibrium CO tension by about 2×10^{-3} mm Hg. Table III contains gas data from the SSS together with the expected CO contamination of the chamber gas calculated from the average COHb level of the crew and the analyzed oxygen content of the chamber gas. Identity between these two values was observed after recalibration of the IR instrument before the 7/7 samples, but usually the IR value reported from the chamber analysis exceeded the expected value by 3 to 7 parts per million. No adequate explanation for this discrepancy is apparent as in many cases the reported IR value actually exceeded the equilibrium value, a situation which certainly did not exist at any time in the 90-day test as evidenced by the failure of the COHb of the crew and the CO content of the gas phase to increase as rapidly as would be required with the measured rate of endogenous CO production.

CONCLUDING REMARKS

These results demonstrate that hemoglobin solutions prepared from blood clots may be used to accurately determine the fractional CO saturation of blood. These data, together with the oxygen content of the inspired air may be used to estimate the air CO contamination. In the steady state where endogenous CO production is exactly balanced by CO excretion, the equilibrium pCO of the blood exceeds the pCO of the inspired air by approximately 2×10^{-3} mm Hg. This value is determined by a number of physiological variables including alveolar ventilation rate, lung diffusion capacity, rate of endogenous CO production, and alveolar oxygen tension.

Table III

**Blood COHb saturation and chamber gas relationships
during ninety-day test inside the SSS**

Date 1970	Mission Day	Total Dry Pressure mm Hg	Oxygen Fraction	Average COHb %	P _{Eq} CO calc. mm Hg x 10 ³	f _I CO calc. x 10 ⁶	f _I CO Obs. by IR x 10 ⁶
6/13	1	Men enter chamber					
6/16	4	507.5	0.3153	1.00	5.20	6.8	11
6/23	11	516.0	0.2984	1.55	7.70	11.9	26
6/30	18	509.0	0.3045	1.73	8.68	14.1	24**
7/7	25	509.0	0.3045	1.64	8.22	13.1	13
7/14	32	513.0	0.3021	1.80	9.03	14.7	8
7/21	39	505.8	0.3045	1.86	9.30	15.5	12
7/28	28	511.1	0.2994	1.67	8.24	13.1	12
8/4	53	508.0	0.3011	1.63	7.98	12.7	18
8/11	60	504.6	0.3092	1.44	7.35	11.3	20
8/18	67	506.4	0.3060	1.29	6.41	9.4	16
8/19	68	Toxin burner turned off					
8/25	74	507.1	0.3060	1.90	9.58	16.0	22
9/1	81	511.5	0.3126	2.33	11.78	20.5	27
9/1	81	Toxin burner turned on after 9/1 samples					
9/8	88	499.4	0.3120	1.93	9.71	16.7	15
9/11	91	503.7	0.3081	1.80	8.96	15.0	18
9/11	91	Men leave chamber					

**Error in calibration of IR instrument discovered.

The toxin burner used in the SSS was effective in removing CO sufficiently rapidly to prevent accumulation of CO. The crew members were shown to form about 0.59 ml of CO per man hour or approximately 396 ml of CO by the 4 men per week. In the absence of CO removal, toxin burner not operating, the endogenous CO production from the crew can be estimated from the change in the total CO content of the gas phase and the blood of the men.

The data presented indicate clearly that the instantaneous range of COHb in all members of the crew was extremely small. These comparisons were made without regard to exercise or sleep patterns and substantiate the Haldane expression which indicates that the major factor affecting the level of COHb is the ratio of pO₂ to pCO in the alveolar gas.

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SUMMARY AND CONCLUSIONS

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The 90-day manned test of a regenerative life support system has been completed with the accomplishment of the seven major objectives that were formulated during the initial planning of the program. The data obtained are important to the scientific and engineering communities in undertaking the nation's future space effort. These data have been summarized in the preceding papers. Examination of these data is still underway, and useful conclusions will continue to be made for some time to come. However, the following conclusions and recommendations may be made from the evaluations that have been undertaken to date:

Attainment of program objectives:

- (1) The 90-day test was completed without resupply of expendables or equipment; hence the biological and chemical isolation of the space station simulator (SSS) was maintained.
- (2) The regenerative life support systems operated effectively in producing potable water, removing atmospheric contaminants, and recovering oxygen from carbon dioxide.
- (3) Provisioning of spares, tools, and expendables permitted mission completion.
- (4) Data were obtained that defined system and subsystem mass and thermal balance and power requirements.
- (5) All maintenance and repair of the onboard equipment were conducted by the test crew.
- (6) Data on planning and procedures and corresponding crew performance were obtained and can be used to determine the capability of man in performing in-flight experiments during space missions.
- (7) Data were obtained on physiological and psychological effects of confinement on the test crew, including group dynamics and the effectiveness of planned work and rest cycles.

Evaluation of advanced subsystems:

- (1) Data were obtained on the performance of the vacuum distillation and vapor filtration unit, the solid amine CO₂ concentrator, the water

electrolysis units, the two gas controls, and a mass spectrometer atmosphere sensor.

- (2) Further development of water electrolysis is necessary to meet flight operational reliability requirements.
- (3) Incidents occurred during which several units were subjected to transient output demands which exceeded their capacity. This result emphasized the requirement for subsystem designers to provide for adequate margin to allow recovery from high loads, and for systems integrators to specify design parameters that minimize transient demands.

Subsystem performance:

- (1) The relative importance of various unit performance characteristics was emphasized by integrated system testing but frequently was not pointed out by subsystem design studies or test experience.
- (2) The results of the material selection program and performance of the trace contaminant removal equipment were such that the atmospheric contaminants were, in most cases, lower than those found in normal ambient atmosphere.

Food management:

- (1) Freeze dried diet could be acceptable for long missions.
- (2) Frozen food and selected snacks can be utilized in order to improve crew morale.
- (3) Microwave oven was important for acceptability of food.
- (4) A method for reusing dishes and reprocessing food waste water is required.
- (5) Glycerol drink was accepted by crew and no adverse effects were noted.

Waste management:

- (1) The commode was acceptable to the crew.
- (2) An improved urine collection, measurement, and sampling equipment are required for zero gravity use.
- (3) An improved means of handling waste and garbage is required.

Equipment operation, maintenance, and repair:

- (1) Crew performance in operation, maintenance, and repair of equipment was effective and frequently ingenious.

- (2) Automatic collection and display of data require improvement, particularly inside the space station simulator, to improve crew operational capability.

Habitability:

- (1) The crew was able to adapt to and accept the living accommodations.
- (2) Crew recommended provision of abstract wall pattern (for example, wood paneling) on future missions to break visual monotony.
- (3) Crew would have appreciated shower bath facility.
- (4) Microwave oven and food freezer were important habitability features.

Crew selection and training:

- (1) Crew selection criteria were established and provided effective qualitative guidance during the selection process because they were
 - (a) Developed early in program
 - (b) Provided effective guidance during selection process
 - (c) Established an adequate local pool for subject selection
- (2) Crew training was adequate for support of mission objectives with the following exceptions:
 - (a) More time, earlier in training program, would have improved crewmen's effectiveness during early test period
 - (b) Availability of life support equipment earlier in training program was desirable

Manned mission activity analysis:

- (1) Langley space station mission module computer program is capable of providing operationally acceptable activity schedules and facilitated incorporation of last minute changes.
- (2) Computerized activity scheduling is recommended for use in planning future manned tests in preference over manual scheduling.
- (3) Early start in task analysis and definition of constraints are important.

Behavioral studies:

- (1) Results indicate general low level of stress during test.

- (2) Overt inter- and intra-crew hostility seldom occurred.
- (3) Crew showed decreasing morale through day 70; after that day some improvement was shown.

Noninterference performance assessment (NIPA):

- (1) NIPA appears to provide a method for evaluating crew psychosocial integrity on a real-time basis by observational techniques.

Acoustic studies:

- (1) No general change in crewman sensitivity to noise.
- (2) Some loss in threshold hearing levels occurred in two crewmen.
- (3) Crew quarters noise level was acceptable (Acceptance level \approx NCA 55).
- (4) Equipment area noise level was marginal (Acceptance level \approx NCA 70).

Electroencephalograph (EEG) - sleep studies:

- (1) Methodology was developed for obtaining and automatically scoring of EEG sleep records.
- (2) Sleep records show little deviation from norm.
- (3) EEG/sleep analysis would provide valuable assistance in assessing crew mood changes.

Medical program:

- (1) There were no detectable adverse medical effects resulting from the 90-day test.
- (2) Serum calcium and urine calcium were inversely related to CO₂ partial pressure.

Microbiology:

- (1) There was no clinical illness related to carriage or transmission of potentially pathogenic microorganisms.
- (2) The microbiological findings support the growing body of evidence that ground-based closed chamber tests do not markedly affect the microorganisms or the sensitivity of the host to them.

Radioisotope utilization:

- (1) Handling and storage of radioisotope heat sources in a closed environment does not present a hazard to personnel.

- (2) Better operational methods of measuring changes in body fluid volumes are necessary for space flight use.

Recommended areas for improvement:

- (1) Zero G phase separators need to be improved.
- (2) Data collection and display should be automated.
- (3) Better design of cold-water dispenser is required for microbial control.
- (4) Closed-end crew tasks should be scheduled.
- (5) Methods of dishwashing and reprocessing food waste water need to be developed.
- (6) Onboard laboratory should be expanded to reduce sample pass-out requirements.
- (7) The standards for potable water and atmosphere contaminants should be reassessed.
- (8) The criteria for wash water should be defined.
- (9) Crew habitability in the areas of lighting, privacy, shower facilities, and color scheme should be improved.



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